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This report evaluates an alternate method of measuring thrust in the sea level test cell. The method does not require a test cell thrust correction factor which is generally used with the conventional engine installation. In the decoupled bellmouth technique, the bellmouth is isolated from the thrust measuring system, and the inlet momentum is computed from the pressure measurements in the inlet duct. A TF34 engine was tested at an outdoor test site and in a test cell using both thrust accounting methods. Test results show the decoupled bellmouth method worked very well. The method can be used in any test cell or an outdoor test site and should be considered as a good alternative to test cell correlations.

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DECOUPLED BELLMOUTH - AN ALTERNATE METHOD OF MEASURING THRUST IN THE SEA LEVEL TEST CELL

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1.0 INTRODUCTION

This report covers the results of an experiment designed to provide an alternate method of measuring engine thrust in a sea level test cell. The Naval Air Systems Command (NAVAIR) authorized the Naval Air Propulsion Center (NAPC) to conduct this work by Work Unit Assignment No. 463, Appendix A. The primary objective was to demonstrate an alternate thrust measuring technique which could be used in a sea level test cell without a cell thrust correction factor.

In the alternate method of thrust accounting, the bellmouth is decoupled from the thrust measuring system and the inlet momentum and the pressure area forces are calculated from pressure measurements. This is not a new concept. It has been used in most altitude test facilities for some time. Some of the major reasons why this approach was not applied previously to sea level test cells are: (1) a requirement for more extensive inlet instrumentation and more involved calculation procedures, (2) a change to the inlet duct-to-bellmouth mounting scheme and (3) a common belief that because part of the thrust was based on a calculation the final result had to be less accurate. These issues are discussed in the report.

In a conventional engine installation, in either an outdoor test stand (OTS) or in a sea level test cell, the bellmouth is directly attached to the engine and the assembly is mounted on the thrust bed. This concept is based on the premise that the net force on the bellmouth is zero, i.e., when the bellmouth air approach velocity is low and uniform, the bellmouth suction force is balanced by the inlet momentum force. In an OTS, on a windless day, the measured test stand force is equal to the engine net thrust. However, these ideal conditions do not exist in the test cell; consequently, some correction to the measured thrust is generally required. The thrust correction factors may be derived (1) by correlation with OTS test results using the same engine, (2) by calibration with an exhaust nozzle that has well-defined performance characteristics and (3) by other semi-empirical methods based on test cell flow-field measurements. The test cell thrust correction factors which are in use at various Naval activities are based on correlations with OTS. The correlation process is time-consuming and costly. It requires a dedicated engine and a coordinated effort of several different activities.

A series of back-to-back engine calibrations was performed in the NAPC test cell and at the OTS using both thrust measuring methods. Results show that thrust measurement accuracy of the two methods is about the same.

2.0 DESCRIPTION OF TEST EQUIPMENT

2.1 ENGINE

The TF34-GE-400 turbofan engine is a dual-rotor front-fan configuration with a bypass ratio of 6.23. It has a single-stage fan with a pressure ratio of 1.51 to 1 and a 14-stage axial-flow compressor with variable stators and a nominal pressure ratio of 14.5 to 1. The combustor is an annular type. The gas generator (core engine) high pressure turbine has two axial-flow stages, both air-cooled. The fan low pressure turbine has four axial-flow stages and drives the fan through a concentric shaft passing forward inside the core engine rotor. The engine mounted accessory gearbox, driven through the six o'clock front frame strut off the gas generator rotor, provides a maximum combined hydraulic and electrical power extraction capability of 285 shaft horsepower. The lube system, including engine oil tank, is completely self-contained. The fan nozzle is an engine component. The engine provides bolted flanges for connection of the aircraft primary exhaust nozzle and attachment of aircraft cowling.

The Naval Air Rework Facility (NARF), Alameda, provided the TF34-GE-400B engine, S/N 202039, to NAPC. We calibrated the engine at OTS using conventional installation as part of the NAVAIR Work Unit Assignment No. NAPC 177. Results of this test were reported to NAVAIR in December 1984. Subsequently, the same engine, pylon, cowling, exhaust nozzle, bellmouth and screen were used for this program.

The TF34 engine is a good choice for evaluating the test cell effects on measured engine performance because its airflow is high (340 lb/sec) and the fan nozzle is unchoked at the sea level, static conditions. Generally the test cell thrust correction factor increases with airflow. Another concern is that the engine mass flow and hence thrust may be influenced by the test cell enclosure.

2.2 INSTALLATION

The three different engine installations used in this evaluation are shown in Figures 1, 2 and 3. In each case the engine was mounted on a thrust balance stand to facilitate measurement of the net test stand force. The same inlet bellmouth and screen, pylon, cowling and exhaust nozzle were used in each test setup. The installations differed only in the bellmouth-to-engine connection. In a baseline or conventional installation, the bellmouth was attached to the engine/thrust bed. This configuration mounted in the 2W test cell is shown in Figure 1. The other two installations had a longer inlet duct

with a slip joint (labyrinth seal) at the bellmouth exit which facilitated engine testing with the bellmouth either attached or isolated from the thrust measuring system. Figures 2 and 3 show this configuration installed in the 2W test cell and at the OTS.

It should be noted that for the alternate method, the inlet duct had to be increased by about 66 in. to provide room for pressure profile instrumentation; and the labyrinth seal was needed for uncoupling the bellmouth. At the outset, we had some concern that these changes could cloud the test results. Therefore we incorporated other features into the installation that allowed testing with either the conventional or alternate thrust accounting approach using identical engine inlet flow path. The convertibility features were outside of the engine flow path. These features are described in Figure 3.

The slip joint is needed for the alternate thrust measurement only. However, for this evaluation we kept the slip joint in place for the calibrations that used a conventional thrust accounting method. For one calibration, the slip joint was sealed (wrapped) so that we could assess the impact of air inflow through the joint on engine performance.

Figures 1 and 2 show the TF34 engine installed in the 2W test cell along with test cell dimensions. Air enters through an overhead inlet stack and is directed downward by the turning vanes. The exhaust gases along with the secondary flow are discharged through a telescoping duct to the exhaust stack. The telescoping duct can be positioned fore-and-aft to provide proper scavenging of the exhaust flow. It contains a tubular grid and a water spray system for cooling the afterburner exhaust. For these tests we varied the duct position between the maximum and minimum limits shown in Figures 1 and 2.

2.3 INSTRUMENTATION

Engine instrumentation is shown in Figure 4. Note that the engine sketch in this figure represents a conventional engine installation with the bellmouth directly coupled to the engine. There was no station 1.1 instrumentation with this configuration. It was used in conjunction with the longer inlet duct only. Also, only two pressure rakes are shown at station 2. Midway through the test program we added two more rakes at station 2 when we noted that, in the 2W test cell, the pressure in the upper half of the inlet duct was consistently 0.2 percent lower than the average pressure.

The net force on the test stand was measured by a dual-bridge, 10,000 lb capacity, strain gage load cell. The thrust system calibrations were performed with the engine completely instrumented and installed on the thrust bed. The

system was calibrated at least once with each inlet configuration. Fuel flow was measured with two extended range 5/8-in. turbine-type flowmeters. Pressures were measured by a Scanivalve system. All low pressures were measured by a 5 psi differential pressure module which was referenced to a 15 psi module.

The corrected airflow and the inlet momentum were computed from the pressure and area measurements at station 1.1. Instrumentation at station 1.1 included three wall static taps, and 15 area-weighted total pressure sensors.

An automated data acquisition system was used to record and process the data online. All parameters were displayed in the test cell control room via cathode ray tubes for real-time monitoring and analysis. Engine monitoring instrumentation was displayed on analog-type instruments.

Estimated instrumentation accuracies are included in Appendix B. For the alternate thrust method, the estimated corrected net thrust (FNK) precision and bias errors are $\pm$ 26 lb and $\pm$ 38 lb, respectively. Similarly, for the conventional method of measuring thrust at the OTS, these values are about $\pm$ 20 lb and $\pm$ 11 lb.

3.0 METHOD OF TEST

3.1 THRUST ACCOUNTING PROCESS

For a conventional installation in an OTS, the engine net thrust (FN) is equal to the test stand measured force (F_m) after correcting for tare forces. When the same installation is enclosed, as is the case with the sea level test cells, other forces have to be accounted for.

$$FN = F_m + F_r + F_d + F_b$$

where, F_r = bellmouth force resulting from an unbalance of the bellmouth suction force and the inlet momentum

F_d = scrubbing force on the engine and test stand

F_b = buoyancy force resulting from the test cell pressure gradients.

Generally, the sum of these test cell-peculiar forces is derived by cross-calibrating the test cell with an OTS using the same engine. The resultant test cell thrust correction factor is used in subsequent tests of the same model engine.

In a decoupled bellmouth installation (alternate thrust method) at an OTS or in a test cell, the engine net thrust is related to the measured force as follows:

$$FN = F_m + M_{1.1}V_{1.1} - KA_S\,(P_{amb} - P_{S1.1}) + F_d$$

where, $M_{1.1}V_{1.1}$ = inlet duct momentum at station 1.1

A_S = inlet duct area at the slip joint (outside diameter)

$P_{S1.1}$ = static pressure at station 1.1

P_{amb} = atmospheric pressure for OTS or ambient pressure in aft part of the test cell for 2W

F_d = scrubbing force in an OTS is zero and scrubbing force in 2W was assumed to be negligible.

The inlet duct momentum, downstream of the slip joint, was calculated from total pressure profiles and static pressure at station 1.1 using the following relationship.

$$M_{1.1}V_{1.1} = KA_{1.1}P_{S1.1}\left(\frac{2\gamma}{\gamma-1}\right)\left[\left(\frac{P_{t1.1}}{P_{S1.1}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

where, $A_{1.1}$ = inlet duct area; ft^2

$P_{S1.1}$ = average of three wall static pressures; in. Hg Abs

γ = 1.4

$P_{t1.1}$ = area-weighted total pressure, including boundary layer; in. Hg Abs

$K = 70.727$

As stated previously, the alternate method of thrust accounting has been used in altitude test facilities all along. However, the uncertainty of measured thrust in an altitude cell is somewhat greater than it is for the OTS or the sea level test cell. Note that $P_{S1.1}$ is used to calculate the momentum and the pressure-area forces; and an error in $P_{S1.1}$ will drive both terms in the same direction. In an OTS or in a sea level test cell, the resultant error in the momentum term is offset by the error in pressure-area force. In an altitude test cell, when the simulated flight condition is greater than Mach 0.5, both terms are positive and the resultant errors are additive.

3.2 ENGINE CALIBRATION PROCEDURES

A number of engine calibrations were performed at the OTS and in the 2W test cell with three different engine inlet configurations, as described in the next paragraph. Generally, calibrations were conducted on different days. If two engine calibrations were made on the same day, the engine was shut down and the instrumentation systems were recalibrated prior to the next test. Each calibration consisted of acquiring steady state data at five to 10 power settings in descending and ascending order. Stabilization time was from 7 to 10 min. Tabulated data are included in Appendix C.

A brief description and the purpose of each test configuration are as follows:

a. Bellmouth attached to the engine at OTS - With conventional installation, three engine calibrations were performed as part of the Alameda test cell correlation program. Computer-averaged corrected net thrust (FNK) versus corrected fan speed (NFK) is the baseline to which the results of other test configurations are compared.

b. Bellmouth isolated from the thrust measuring system at OTS - This configuration was designed for the alternate method of thrust accounting. It included a longer engine inlet duct with a labyrinth seal for isolating the bellmouth from the thrust system. The purpose of this test was to evaluate the alternate thrust method in an outdoor test facility.

c. Bellmouth with long inlet attached to the engine at OTS - The internal flow path of this arrangement was identical to configuration b above. However, the bellmouth was supported from the thrust bed to facilitate the conventional method of measuring thrust. The purpose of this test was to assess the influence of the longer inlet duct and labyrinth seal on engine performance. Two engine calibrations were performed with the labyrinth seal open, and one calibration with the seal closed (wrapped) to preclude inflow of air into the inlet duct downstream of the bellmouth.

d. Bellmouth isolated from the thrust measuring system in 2W - This configuration and thrust accounting method was identical to that of item b above. The purpose of this test was to evaluate the alternate thrust method in a sea level test cell.

e. Bellmouth attached to the engine in 2W - This configuration was identical to that of item a above. The purpose of this test was to derive the test cell thrust correction factor for a conventional engine installation. Engine calibrations in 2W were performed with the exhaust collector duct positioned in the two extreme positions shown in Figures 1 and 2.

4.0 ANALYSIS OF TEST DATA AND DISCUSSION

4.1 COMPARISON OF MEASURED THRUST

The corrected net thrust versus corrected fan speed for the various inlet configurations is compared to the baseline in Figures 5, 6 and 7. The baseline is derived from a computer fit of three calibrations conducted at OTS with conventional engine installation. In each figure the baseline is depicted by a dashed line. Similarly, the solid line is a curve fit of all data points for a specific inlet configuration.

Figure 5 shows measured engine performance at OTS with the long inlet duct and with the baseline inlet. Based on these results we conclude that the longer inlet duct and the labyrinth seal had a negligible influence on measured thrust. The maximum observed disagreement of 30 lb is within the expected uncertainty band.

The corrected net thrust for the decoupled bellmouth installation at OTS, using the alternate method of thrust accounting, is compared to the baseline in Figure 6. Both methods yield the same results.

The basic difference between the two methods of measuring/deriving thrust is discussed in Section 3.1. Examples of actual values are as follows:

For conventional installation (baseline)

$FN = F_m = 9100$ lb for NFK of 6745 RPM;

and for isolated bellmouth (alternate method)

$$FN = F_m + M_{1.1}V_{1.1} - A_S\,(P_{amb} - P_{S1.1}) = 7107 + 4722 - 2758$$

$$= 9071 \text{ lb for NFK of 6745 RPM.}$$

Note that for isolated bellmouth, the measured test stand force is significantly lower than for the conventional method. The inlet duct momentum and the pressure-area forces which are calculated from pressure and area measurements account for the difference in measured force.

The test results from calibrations performed in 2W test cell are compared to the baseline in Figure 7. The decoupled bellmouth data track the baseline quite well. Note that the baseline as well as other calibrations at OTS were performed with an average inlet temperature 34°F lower than in 2W. For this reason the OTS data extend to a higher corrected fan speed. The 30 lb difference between the two thrust measuring methods is within the expected uncertainty limits. At the outset, we assumed that the test cell thrust correction was primarily due to an unbalance of inlet momentum and pressure-area force at the bellmouth and that the test stand/engine scrubbing force (drag) was negligible. The test results confirm these assumptions. Therefore we conclude that the alternate thrust accounting method can be used to measure engine thrust in our sea level test cells without any cell correction factor.

The test data for conventional engine installation in 2W are also shown in Figure 7. The difference between the baseline and the conventional installation is the test cell thrust correction. It varies from 330 lb at 6560 RPM to 240 lb at 5650 RPM.

Correlation of net thrust to other thrust indicating parameters (corrected fuel flow, WFK and fan pressure ratio, P2.4/P2) is shown in Figures 8a through 9c. There is a good agreement between measured thrust at OTS and 2W with decoupled bellmouth, Figures 8b and 9b. Figures 8c and 9c show the test cell thrust correction values based on WFK and P2.4/P2 correlations. Ideally, these values, along with the NFK-based thrust correction, Figure 7, should all be the same. The NFK and the WFK-based values are nearly equal (330 lb vs. 340 lb at high power) but the P2.4/P2-based value is significantly higher (380 lb). The primary reason for these differences is due to the measurement accuracies of the thrust indicating parameters. The total uncertainties (2x precision error + bias error) of the NFK, WFK and P2.4/P2-based thrust correction factors are $\pm$ 86, $\pm$ 91 and $\pm$ 144 lb, respectively.

As noted previously, we positioned the exhaust collector duct between the maximum and the minimum values shown in Figures 1 and 2. We observed no difference in measured engine performance due to duct position.

In 2W, with either installation, the secondary airflow around the engine was not as expected. We did not map the test cell velocity profiles, but with the aid of tufts we observed the following anomalies:

a. Upstream of the bellmouth the flow appeared normal (radial into the bellmouth), except at the bottom, where there was a very strong aft component.

b. About 2 ft downstream of the bellmouth lip and 2 ft from the inlet duct, on the left-hand side, the flow was generally up. On the right-hand side, the flow was generally aft.

c. There was some recirculation 2 ft downstream of the bellmouth, at the top. We believe the recirculated air was relatively free of exhaust gases because the temperature on the bellmouth screen was uniform.

In addition, at intermediate power the total pressure in the upper portion of the inlet duct was consistently 0.2 percent lower than the average pressure. This difference was evident on both installations in 2W, but not at OTS. The 2W thrust correction values derived by correlation with OTS account for these anomalies. They are test cell/engine configuration dependent. It is important to note that the alternate thrust accounting method which was used in conjunction with the isolated bellmouth was insensitive to these less than ideal flow conditions.

The noted flow anomalies at the bellmouth are not limited to our test cell. These are typical problems that make up the overall test cell correction factor. Decoupling of the bellmouth isolates these problems from the thrust measurement. The alternate method will not work on installations where severe inlet distortion or vortex ingestion is present. In addition, some test cells may alter the exhaust nozzle flow due to the secondary flow interaction. We believe the alternate method will work on any engine <u>providing the installation does not interfere with normal engine operation</u>.

4.2 COMPARISON OF ENGINE OPERATING CHARACTERISTICS

In the preceding section we have shown that the alternate method of thrust accounting worked quite well at the OTS and in 2W. For this type experiment, however, it is necessary to ascertain that there was no engine deterioration and that test cell effects had no impact on engine operating characteristics. This is especially critical for the high bypass turbofan engines which operate with low fan nozzle pressure ratio. Engine operating characteristics as measured at OTS and in 2W are compared in Figures 10a through 14b.

It should be noted that testing at OTS was conducted with an average inlet temperature about 34^{o}F lower than in 2W. Since the compressor stators are scheduled as a function of high rotor speed and inlet temperature, some variability in the generalized data may be attributed to the inlet temperature changes. Measurement uncertainty is also a factor.

The fan pressure ratio-to-corrected fan speed (NFK) relationship is shown in Figures 10a and 10b. If there was a significant change in the nozzle suppression between operation at OTS and in 2W we would expect a shift in the fan operatng line. The two curves are nearly identical, Figure 10b.

The fuel flow and the high turbine discharge temperature are good indicators of engine deterioration. The OTS data shown in Figures 8a, 11a and 12a extend to higher range because of lower inlet temperature at OTS, but, other than that, we see no significant differences between the OTS and 2W data, Figures 8b, 11b and 12b.

The rotor speed match is shown in Figures 13a and 13b. A direct comparison of these figures shows that in 2W the NFK is about 0.5 percent lower than at OTS. We attribute this difference primarily to the lower inlet temperature at OTS. Figure 13c shows data for one OTS calibration, Run Nos. 15 to 28 of Appendix C (T_o = 55^{o}F), and one 2W calibration, Run Nos. 134 to 146 (T_o = 65^{o}F), during which the inlet temperature had least spread. There is no difference in speed match for these calibrations.

The engine airflow-to-NFK relationship is shown in Figures 14a and 14b. A direct comparison of all 2W and OTS data indicates about 1 percent lower flow in 2W. Again we attribute this difference to the lower inlet temperature at OTS and to the measurement errors. We see no difference in the airflow characteristics between OTS and 2W calibrations which had least spread in the inlet temperature (55^{o}F versus 68^{o}F), Figure 14b.

Based on these results, we conclude that there was no measurable engine deterioration during this test and that the test cell had negligible influence on engine operation.

4.3 APPLICATION OF ALTERNATE THRUST METHOD

The alternate method of thrust accounting may be used in any sea level test cell or an OTS. The primary advantage of this method is that it does not require any cross-correlations with other facilities. In an OTS, this method isolates the wind effects from measured thrust. The disadvantages are a requirement for a more elaborate pressure measuring system and added installation complexity associated with decoupling the bellmouth. This added complexity is the only reason why we do not advocate wholesale conversion of the existing test cells to accommodate the alternate method. However, we do recommend the alternate method be considered when the existing facilities undergo major modifications or in the design of new test cells.

The test hardware, instrumentation and calculation procedures that we used in this demonstration are satisfactory for the test and evaluation type work. For production acceptance test cells, the process can be streamlined significantly. A brief description of salient requirements is as follows.

a. Installation - An engine inlet duct, which is at least 1.5 inlet diameters in length, is supported from the engine/metric portion of the test stand. The bellmouth, which is decoupled from the inlet duct via a slip joint, is supported from a nonmetric part of the test stand. We used a labyrinth type slip joint, although a simpler sleeve arrangement with about 1/8-in. clearance would be adequate. Our bellmouth supporting structure, shown in Figures 2 and 3, was unduly complicated because we used the same hardware for testing both thrust accounting methods.

b. Instrumentation - Pressure measurements which are needed for the alternate method include total and static pressure in the inlet duct and static pressure in the aft section of the test cell. We used 15 pressure probes in the inlet duct to measure the total pressure profile, including boundary layer, and three wall statics. The same arrangement is used in all of our large altitude test cells. Historically, the inlet duct profiles have been flat except in the boundary layer. Generally, accounting for the boundary layer reduces the measured inlet pressure by 0.998 to 0.994 depending on the power setting. Therefore, the total pressure could be measured with about four probes with some adjustment for boundary layer.

c. Measurement Accuracy - In the alternate method, the net thrust is derived from the following relationship.

$$FN = F_m + KA_{1.1}P_{S1.1}\left(\frac{2\gamma}{\gamma-1}\right)\left[\left(\frac{P_{t1.1}}{P_{S1.1}}\right)^{\frac{\gamma-1}{\gamma}}-1\right] - KA_S(P_{amb} - P_{S1.1}) + Fd$$

Influence of measurement errors on FN at the actual operating conditions is as follows:

One percent in F_m (measured force) = 0.78 percent on FN

One percent in A_S (area at slip joint) = -0.30 percent on FN

One percent in $A_{1.1}$ (area of inlet duct) = 0.52 percent on FN

- One percent in P_{amb} (test cell static pressure) = -2.60 percent on FN

  One percent in $P_{S1.1}$ (inlet duct static pressure) = -1.69 percent on FN

  One percent in $P_{t1.1}$ (inlet duct total pressure) = 4.47 percent on FN

  One percent in P_{amb}, $P_{S1.1}$ and $P_{t1.1}$ = 0.22 percent on FN

  Fd (scrubbing force on test stand) - Assumed negligible.

It is apparent that measured pressures, especially $P_{t1.1}$, have a strong influence on FN. Note that FN is less sensitive to pressure measurement errors that have the same value and sign ($\pm$). Therefore, it is important to arrange the pressure measuring system in a way that provides the least differential error between the measurands. We used two multi-port 5.0 psi differential pressure modules to measure all pressures, with one common reference to a 15 psi absolute pressure module.

For the alternate thrust method, at OTS or in 2W, the estimated precision and systematic or bias errors are $\pm$ 26 lb and $\pm$ 38 lb, respectively. For the conventional engine installation at OTS the corresponding values are about 20 and 11 lb. However, if the OTS calibration is to be used for determining the test cell thrust correction factor, other errors have to be taken into account. These include uncertainty related to the thrust indicating parameter, in this case NFK, and other errors introduced during test cell calibration and actual use of the cell correction value. The net result is a significant increase in the bias error. Therefore, we conclude that the overall uncertainty of both thrust accounting methods is about the same.

5.0 CONCLUSIONS

a. The alternate thrust accounting method worked equally well in the OTS and in the 2W test cell without any thrust correction factor.

b. With the alternate method, the values of the thrust measured at OTS and in 2W were within 30 lb of the baseline.

c. The alternate method may be used in any test cell, providing the test cell enclosure does not alter normal engine operating characteristics.

d. The estimated thrust measurement accuracy of the alternate and conventional methods in a sea level test cell is about the same (precision = ± 26 lb and bias = ± 38 lb).

e. For a conventional TF34 engine installation in 2W the thrust correction factor ranged from 330 lb to 240 lb depending on the power setting.

6.0 RECOMMENDATIONS

a. NAPC adopt the use of the alternate thrust accounting method in in-house sea level test cells.

b. NAVAIR initiate a pilot program at one of the NARFs to validate the alternate method in a production environment.

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Definition	Units
A_S	Inlet Duct Area at Slip Joint (Outside Diameter)	sq. ft
$A_{1.1}$	Inlet Duct Area	sq. ft
BAR	Barometric Pressure	in. Hg Abs
F_b	Buoyancy Force	lb
F_d	Scrubbing Force on Engine and Test Stand	lb
F_m	Test Stand Net Force	lb
FN	Engine Net Thrust	lb
F_r	Net Bellmouth Force	lb
K	Corrected to Sea Level Standard Day Conditions	-
K	Conversion Constant - 70.727	lb/in. Hg/sq ft
M	Mass Flow	lb sec/ft
NF	Fan Rotor Speed	RPM
NG	Gas Generator Rotor Speed	RPM
OTS	Outdoor Test Stand	-
P, P_t	Total Pressure	in. Hg Abs
P_S	Static Pressure	in. Hg Abs
SFC	Specific Fuel Consumption	lb/hr/lb
T, TT	Total Temperature	^{o}F or ^{o}R
V	Velocity	ft/sec
WA1.1	Engine Airflow	lb/sec
WF	Engine Fuel Flow	lb/hr
γ	Ratio of Specific Heats	-

LIST OF SYMBOLS AND ABBREVIATIONS (cont'd)

Sybmol	Definition	Units
δ	Pressure Ratio	-
Θ	Temperature Ratio	-
0	Bellmouth Screen Location	-
1.1	Engine Inlet Duct Location	-
2	Engine Inlet Station	-
2.4	Fan Discharge Station	-
5.4	High Pressure Turbine Discharge Station	-

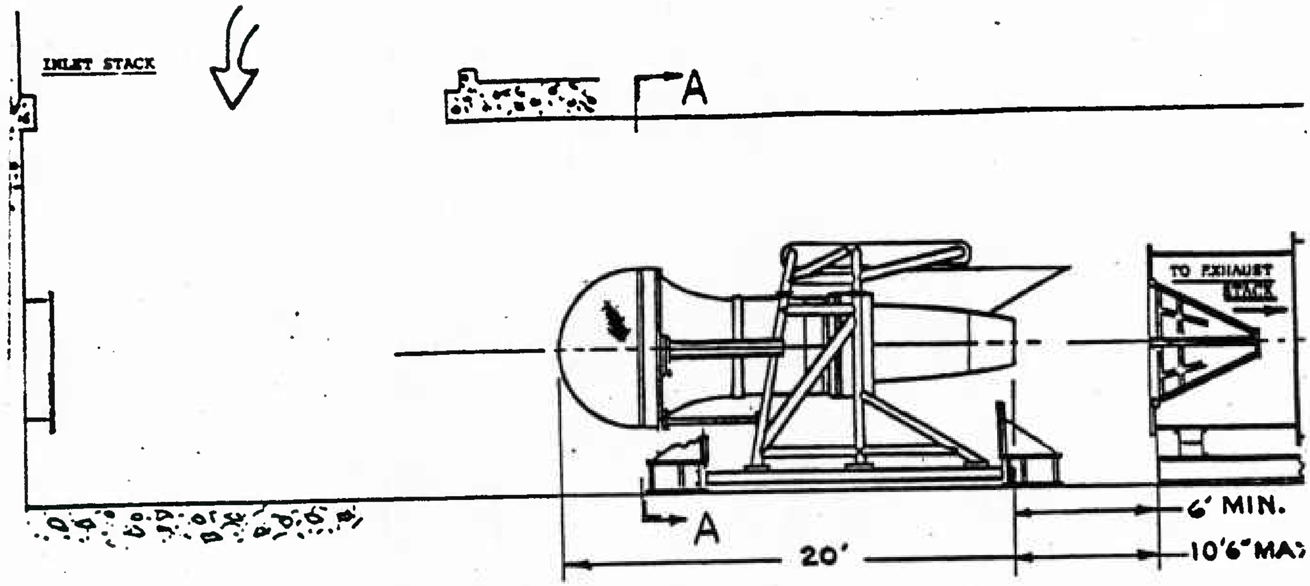

Figure 1. Conventional engine installation in 2W test cell

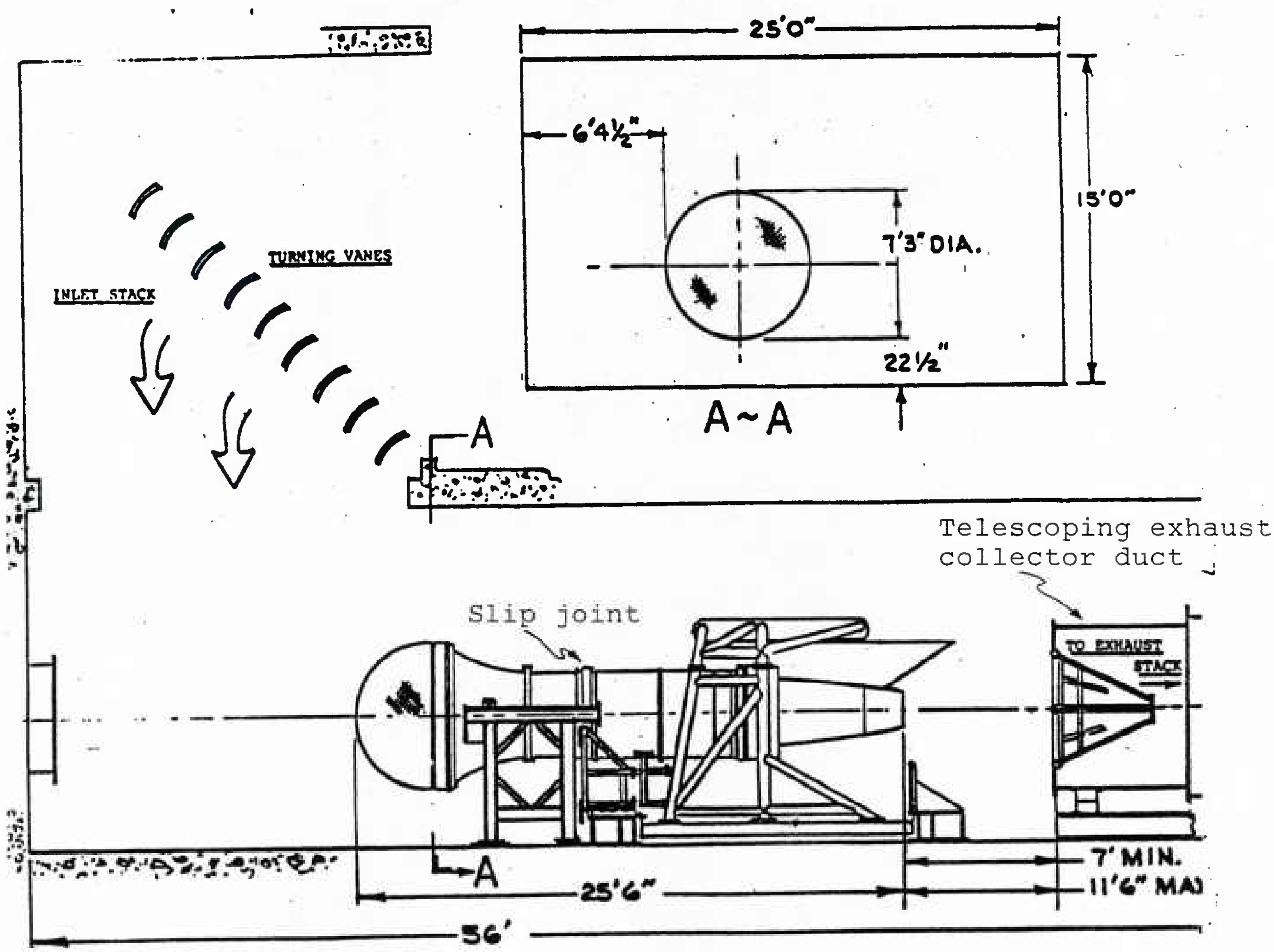

Figure 2. Engine installed in test cell with bellmouth decoupled from the thrust system

Bellmouth attached to thrust system: shims, (2), and cable are installed and shims, (1), are removed

Decoupled bellmouth: shims, (2), and cable are removed and shims, (1), are installed

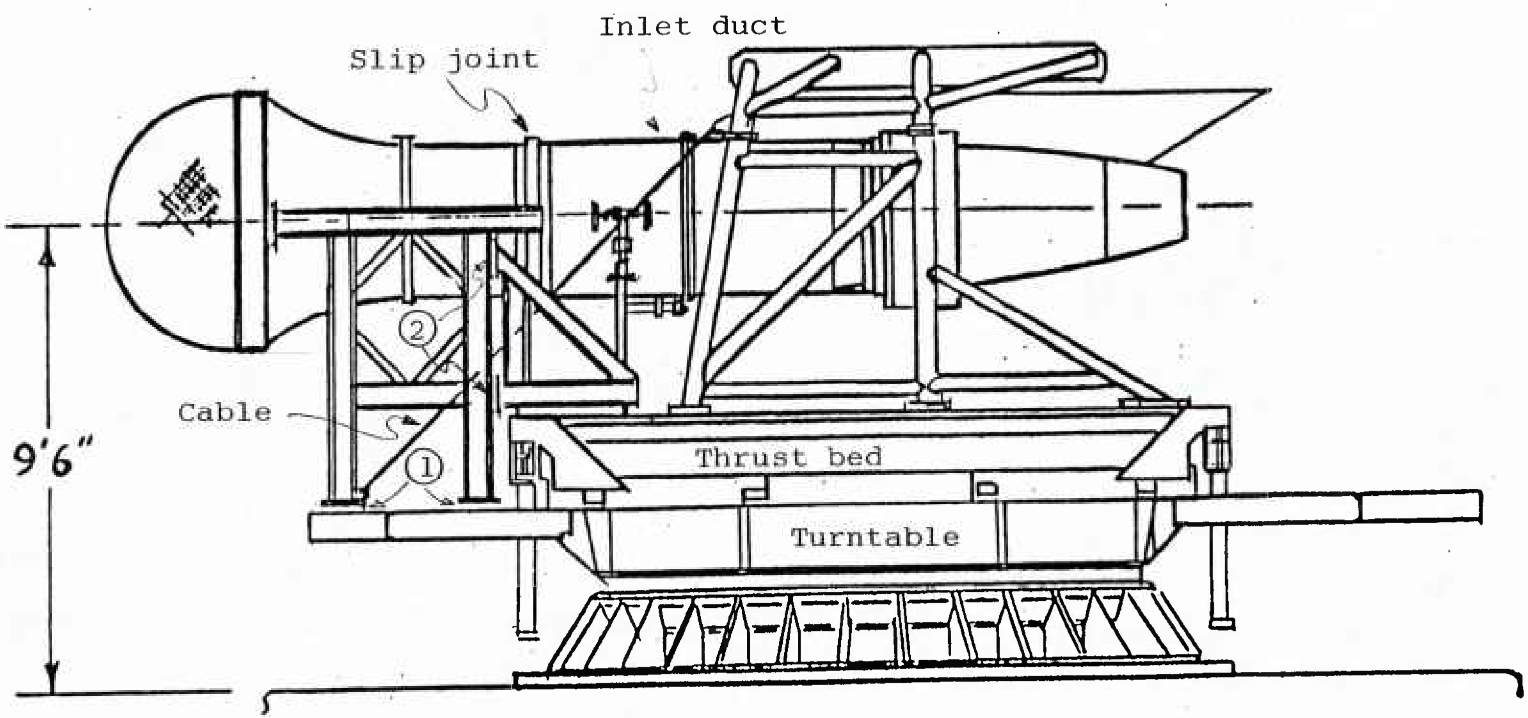

Figure 3. Engine installed in the OTS

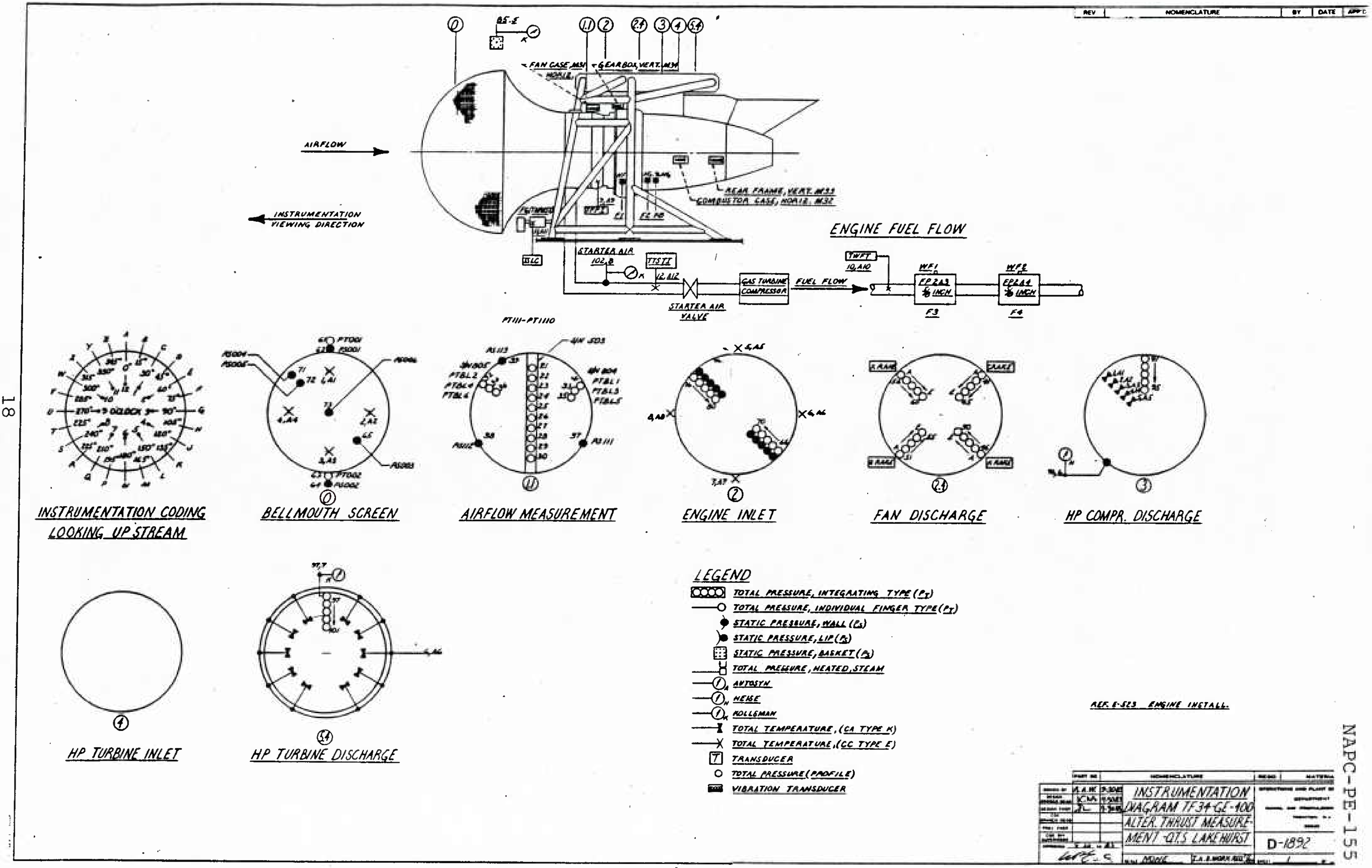

Figure 4. Instrumentation diagram

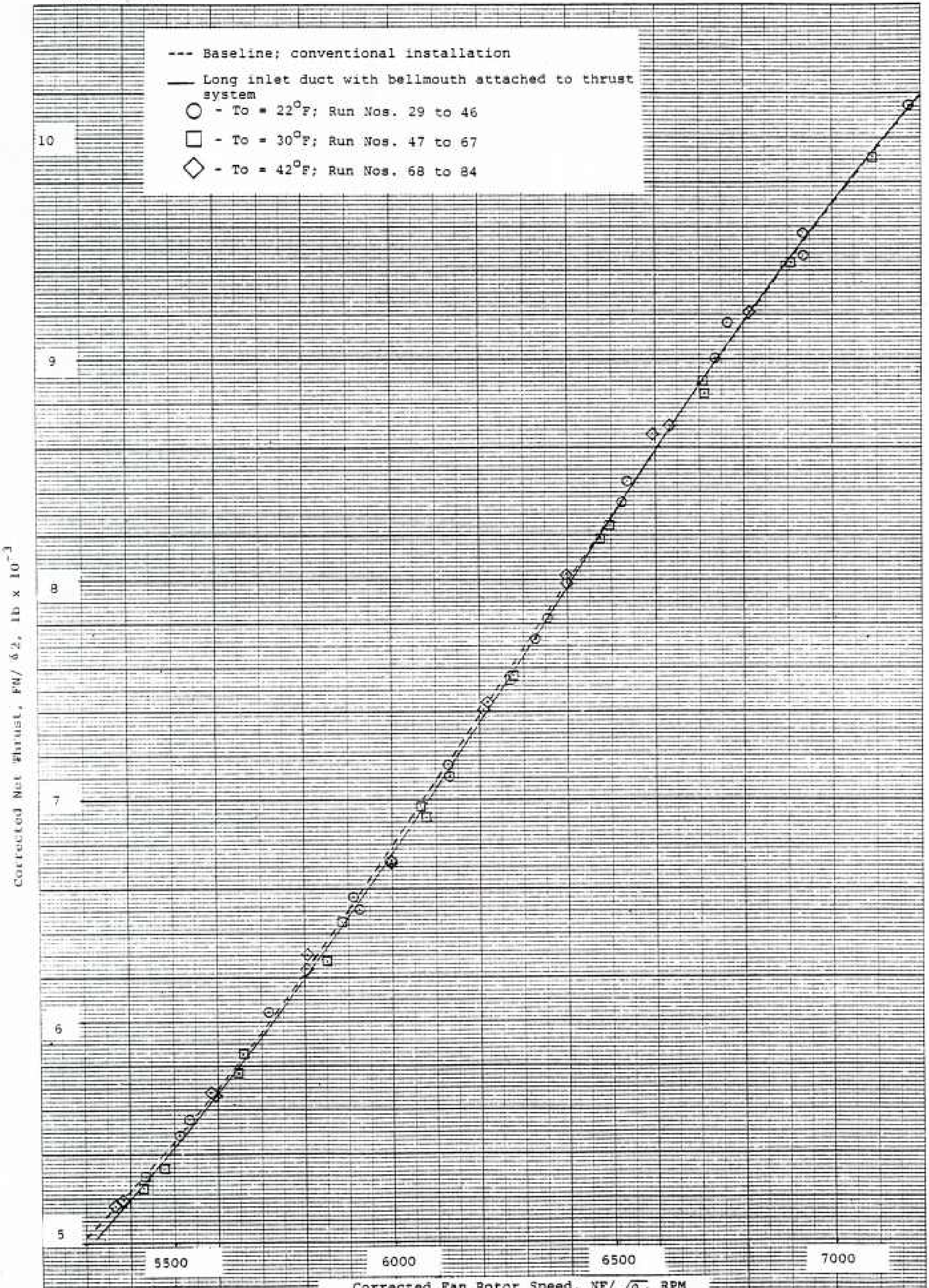

Figure 5. Influence of longer engine inlet duct on measured thrust (OTS)

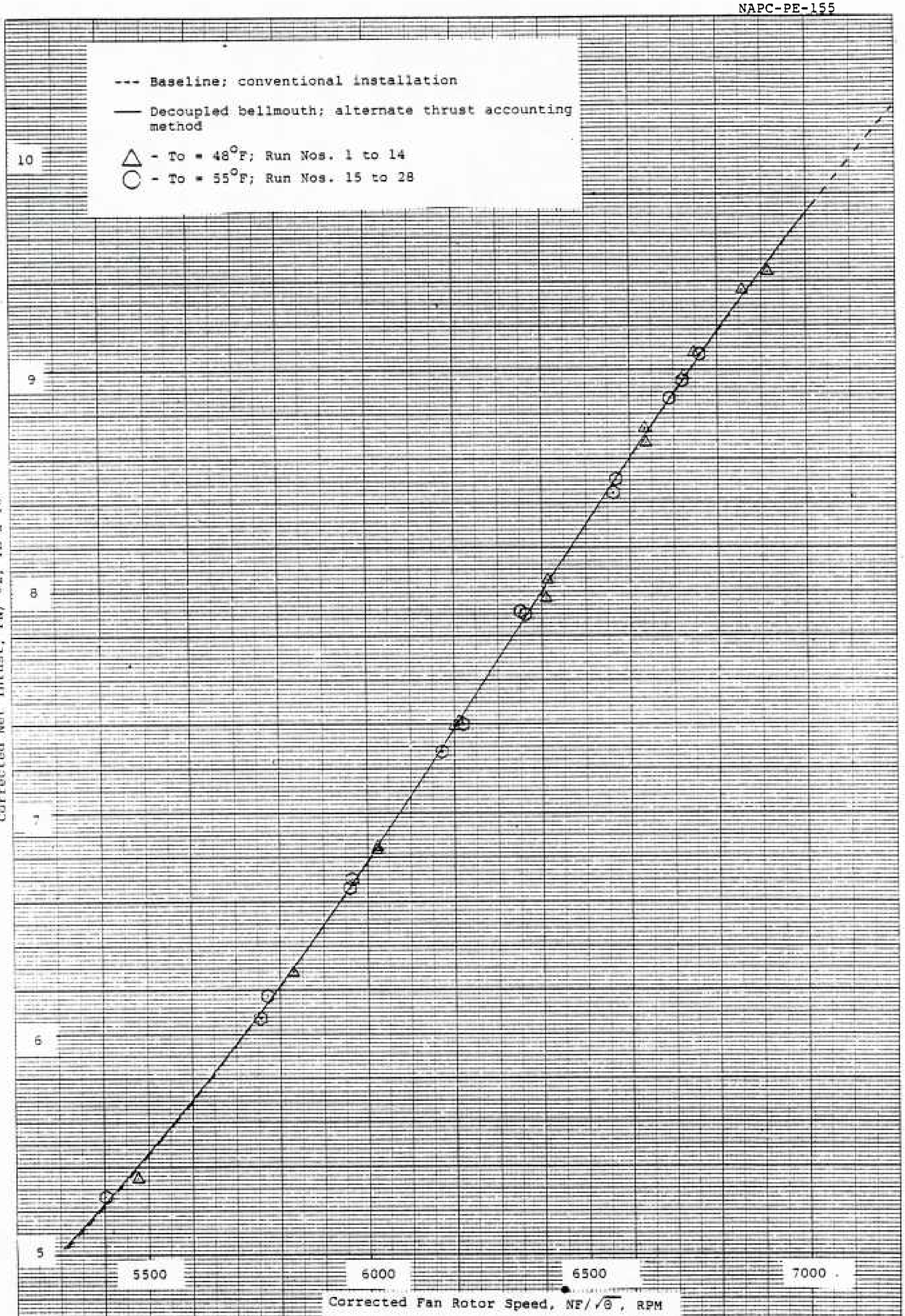

Figure 6. Comparison of conventional and alternate method of thrust accounting at OTS

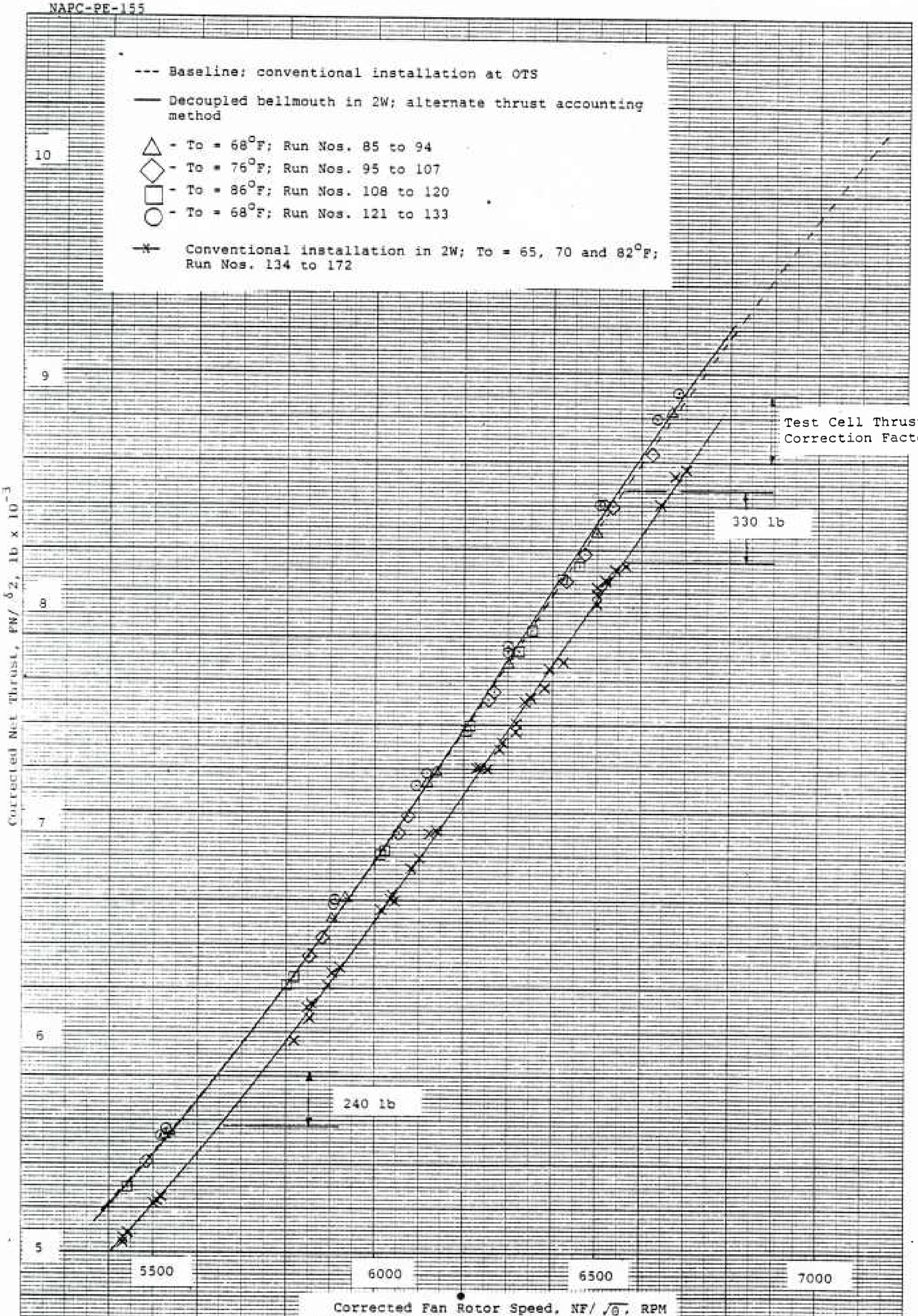

Figure 7. Comparison of conventional and alternate method of thrust accounting in 2W test cell

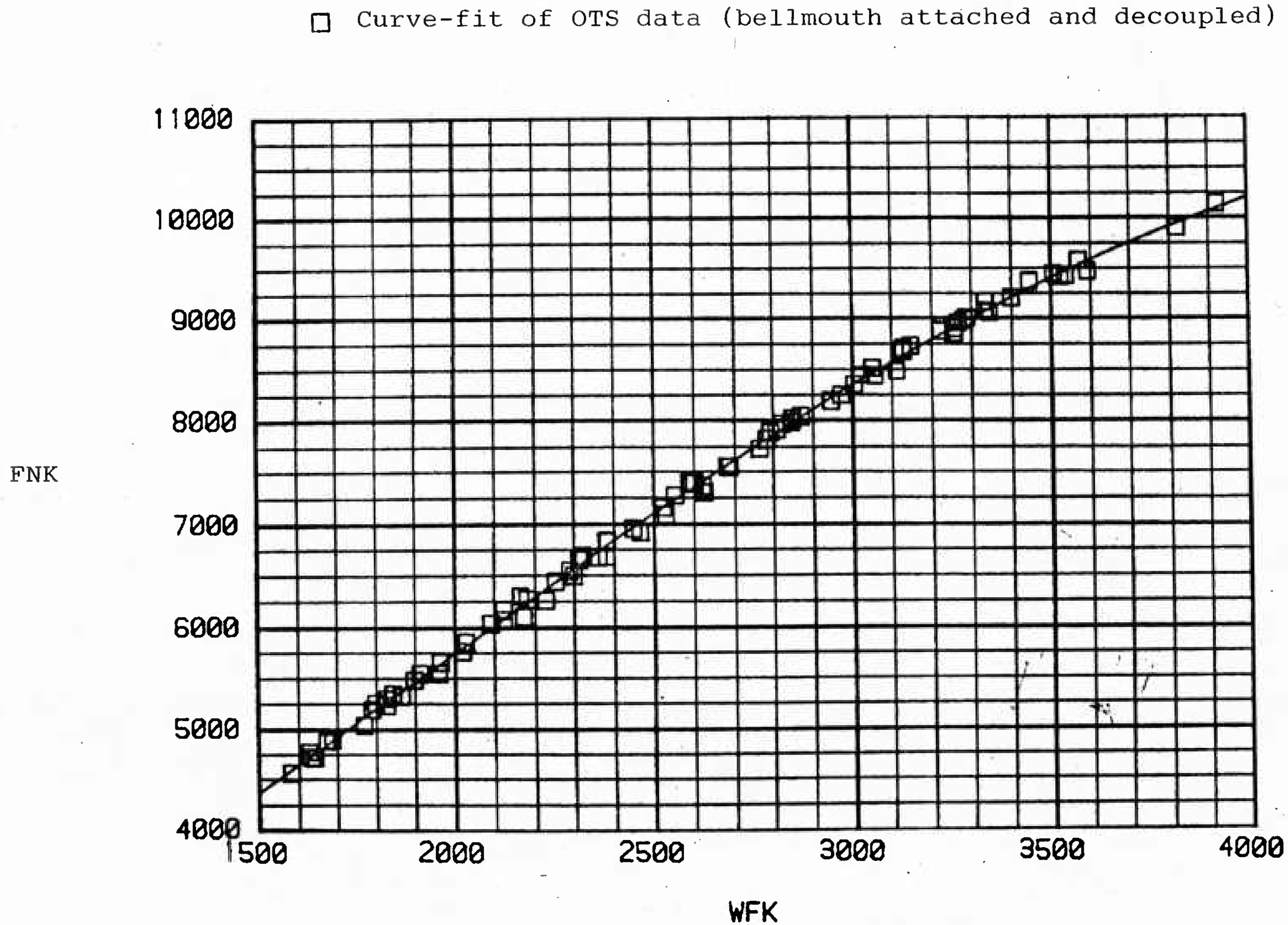

Figure 8a. <u>Corrected net thrust versus corrected fuel flow at OTS</u>

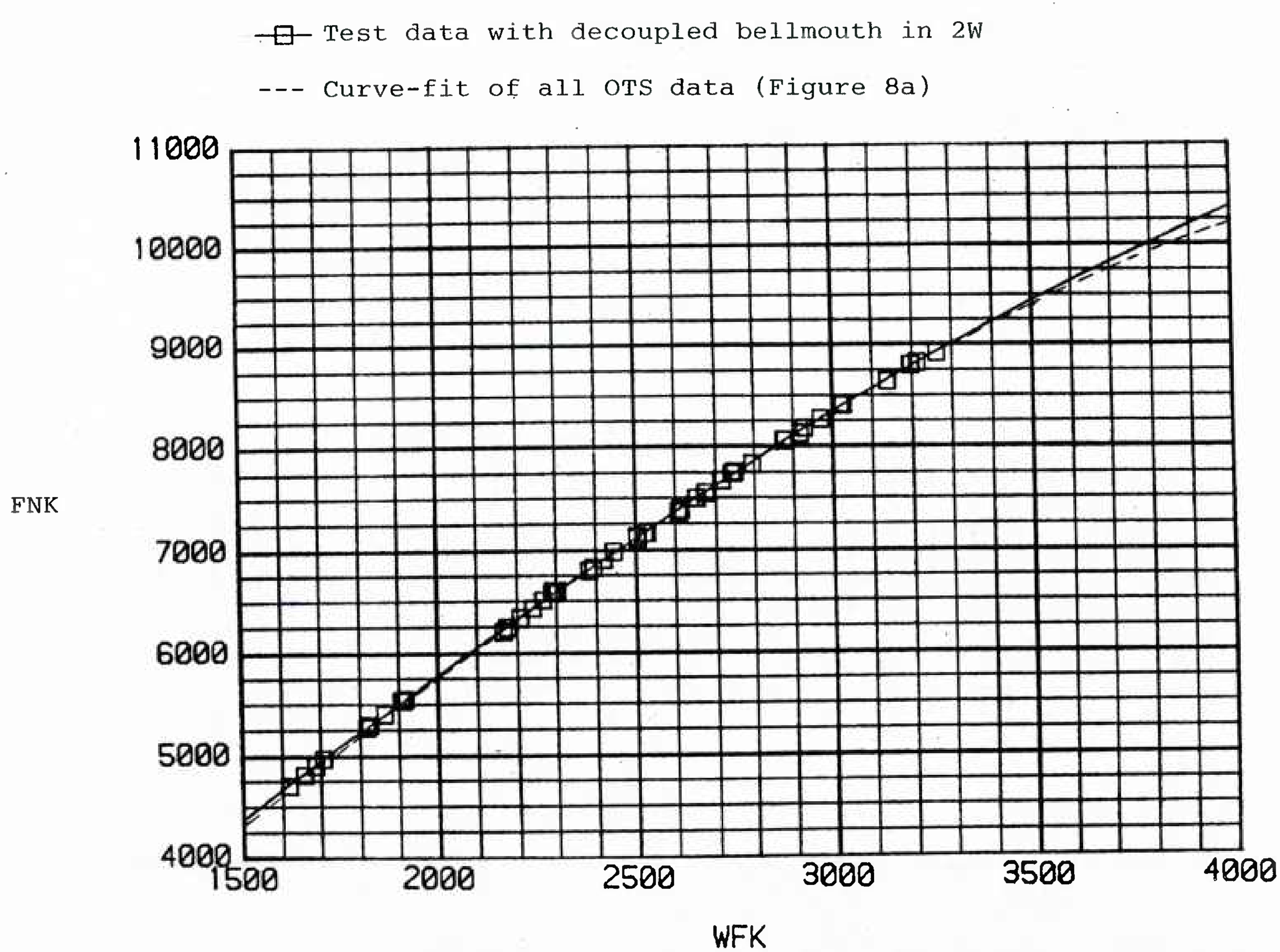

Figure 8b. <u>Comparison of measured engine performance at OTS and in 2W with decoupled bellmouth</u>

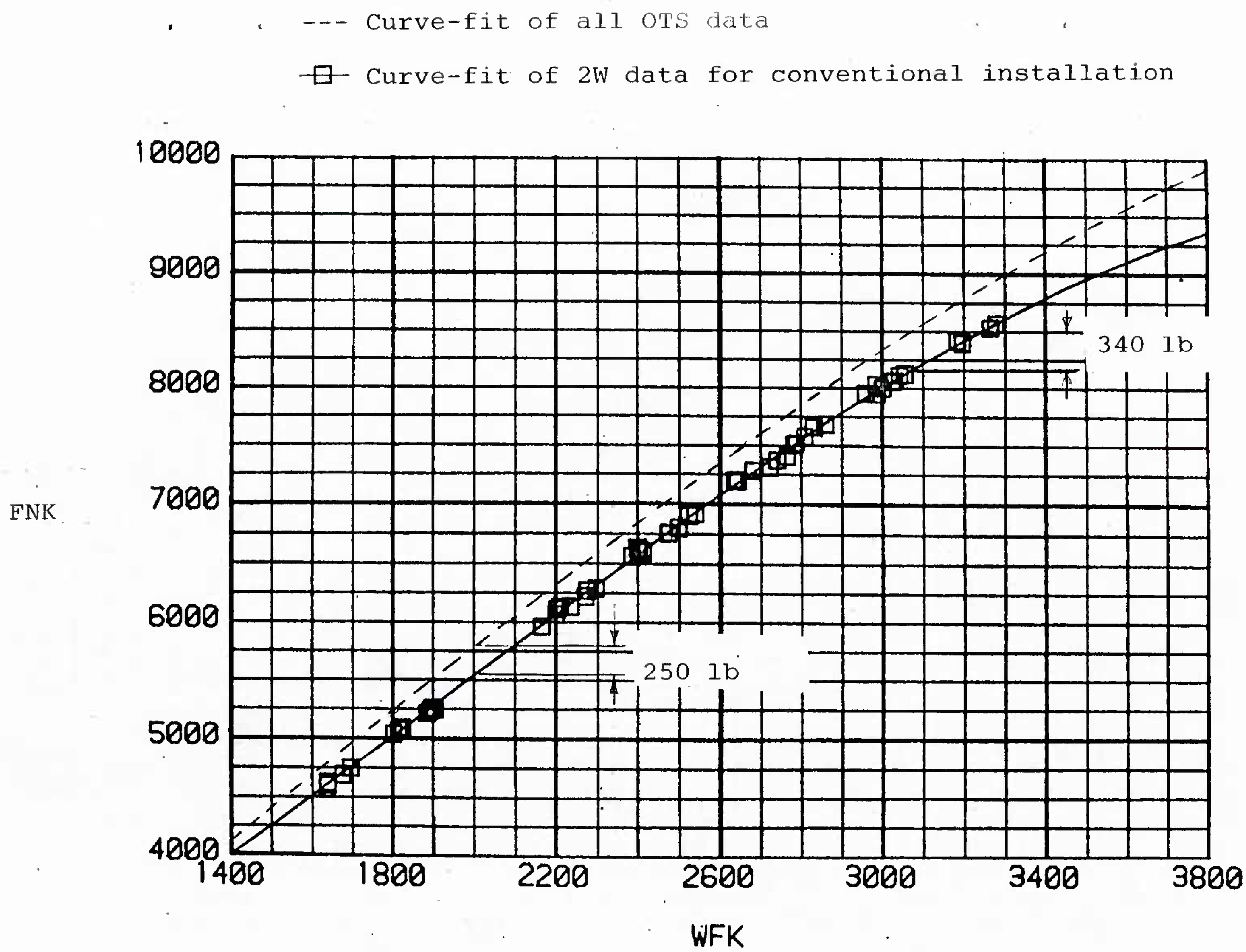

Figure 8c. Test cell thrust correction factor based on fuel flow correlation

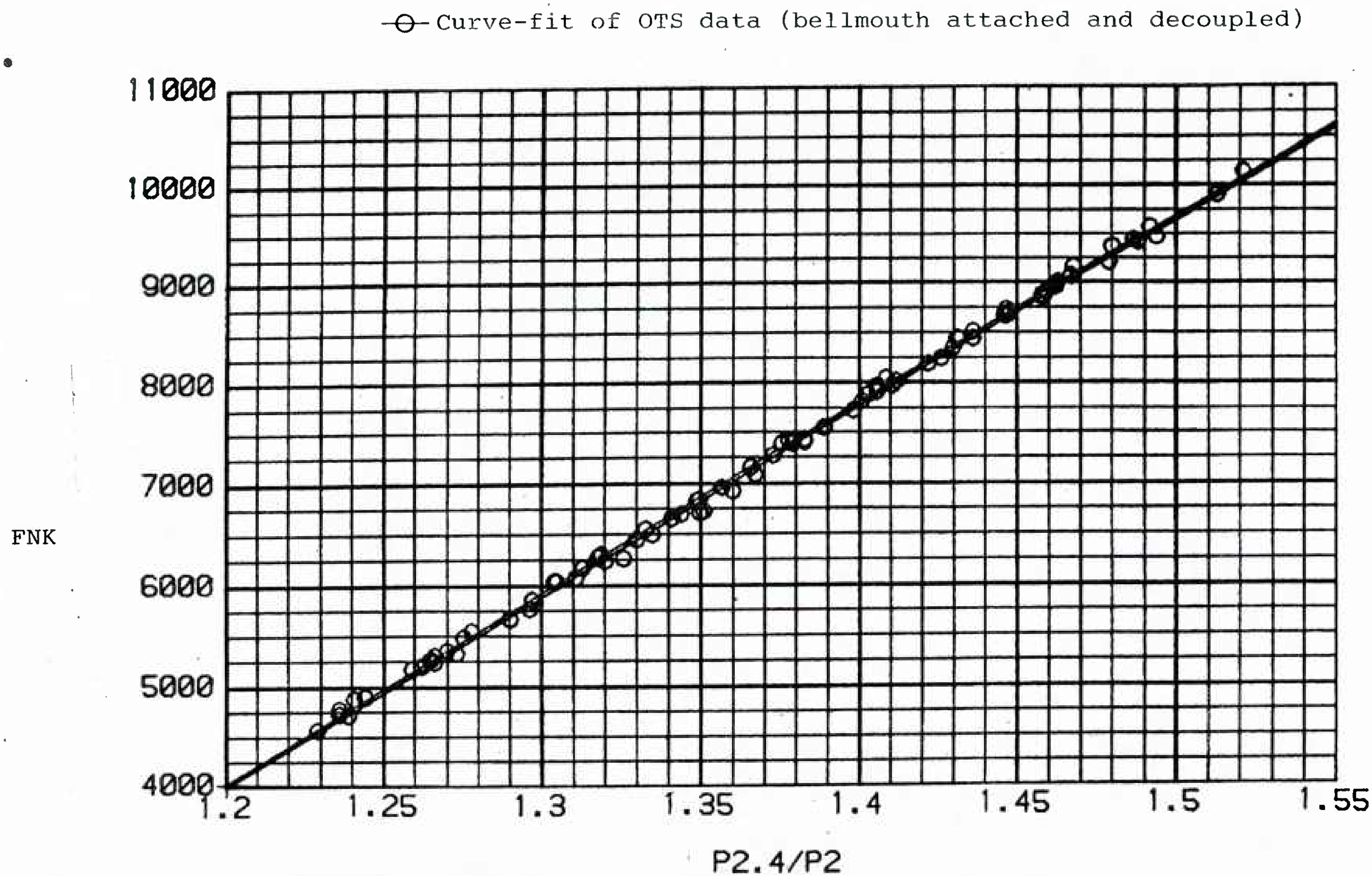

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Figure 9a. <u>Corrected net thrust to fan pressure ratio correlation at OTS</u>

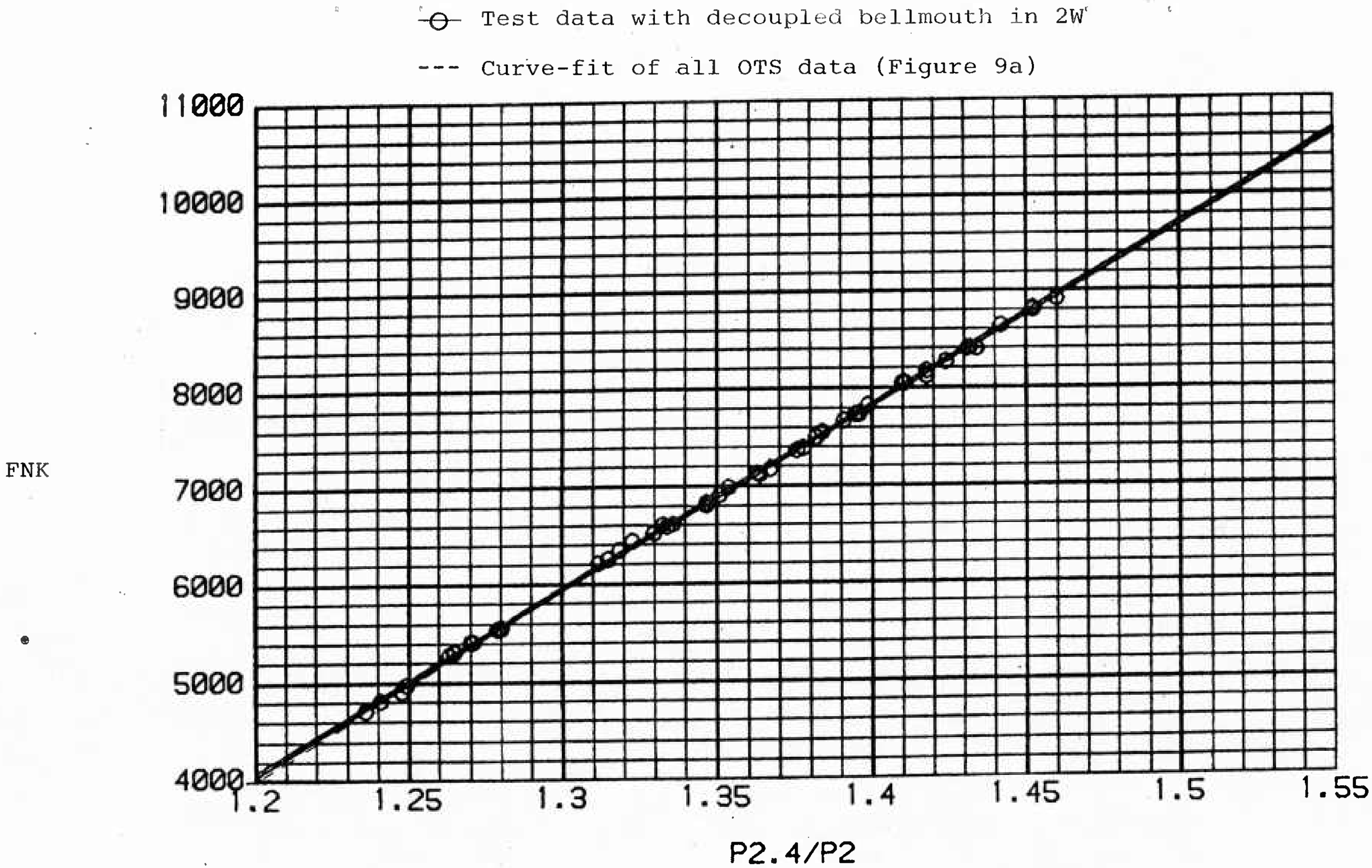

Figure 9b. Corrected net thrust to fan pressure ratio correlation in 2W with decoupled bellmouth

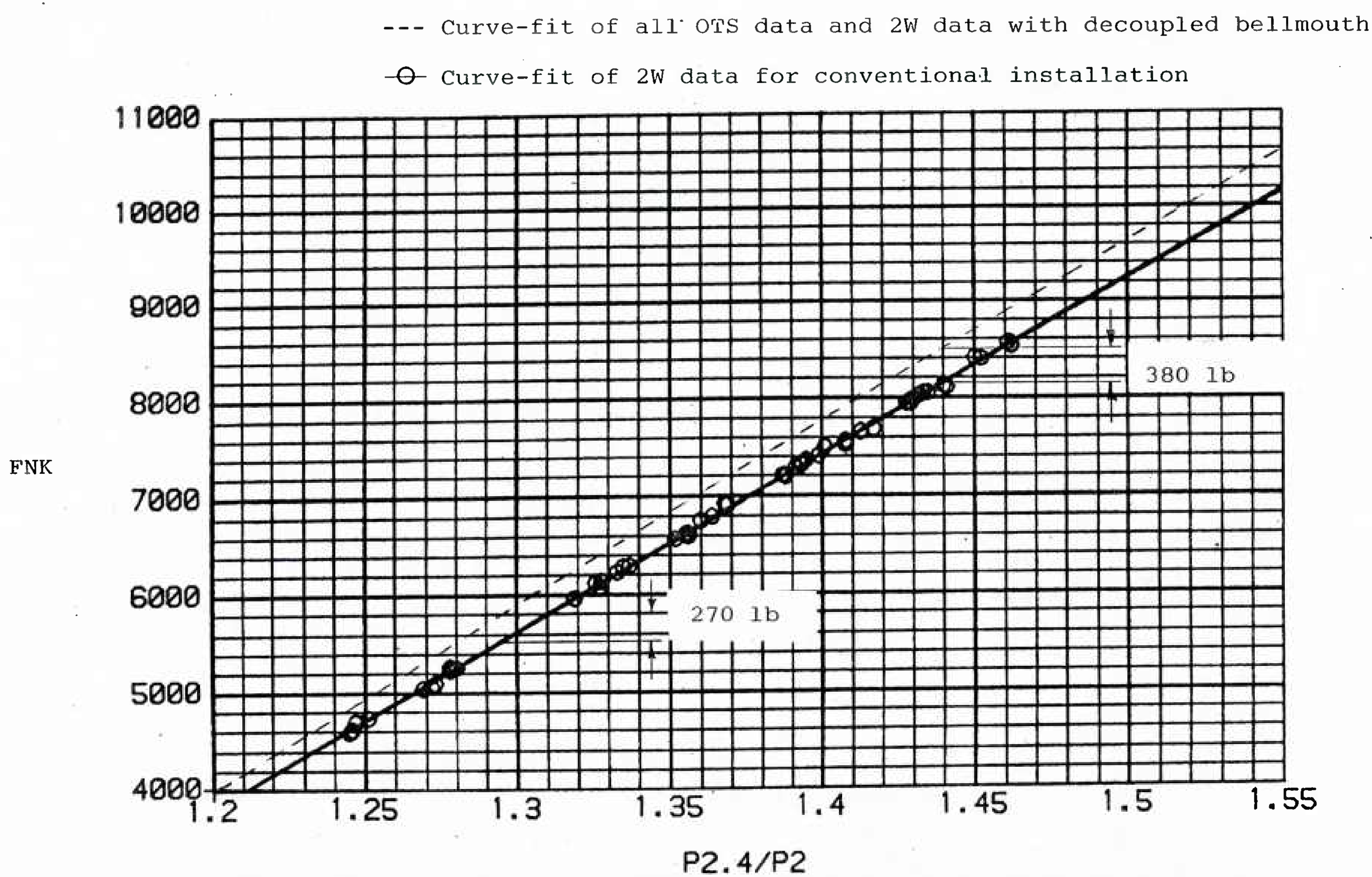

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Figure 9c. Test cell thrust correction factor based on fan pressure ratio correlation

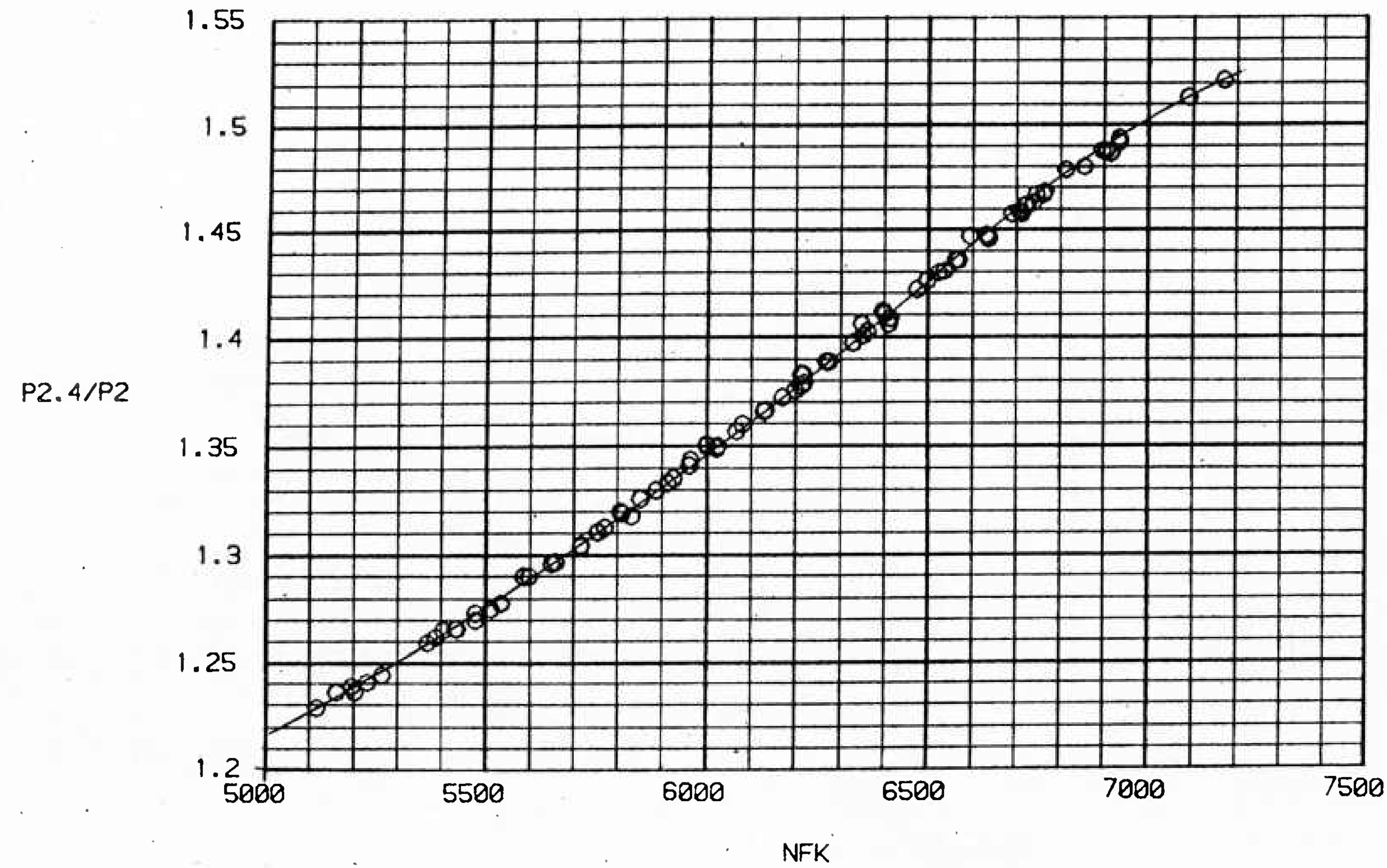

Figure 10a. Fan pressure ratio versus corrected fan rotor speed at OTS

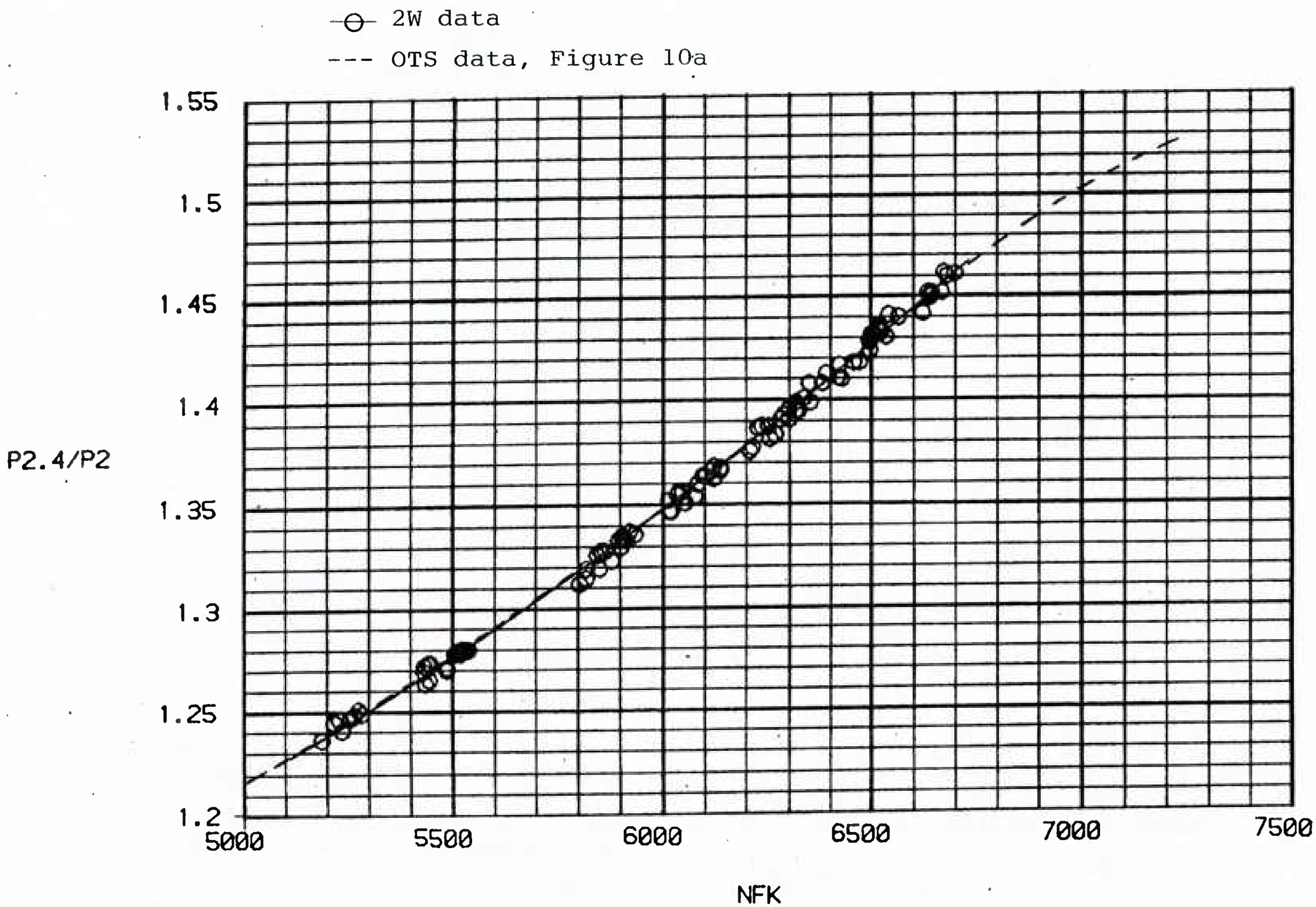

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Figure 10b. Comparison of fan pressure ratio at OTS and 2W

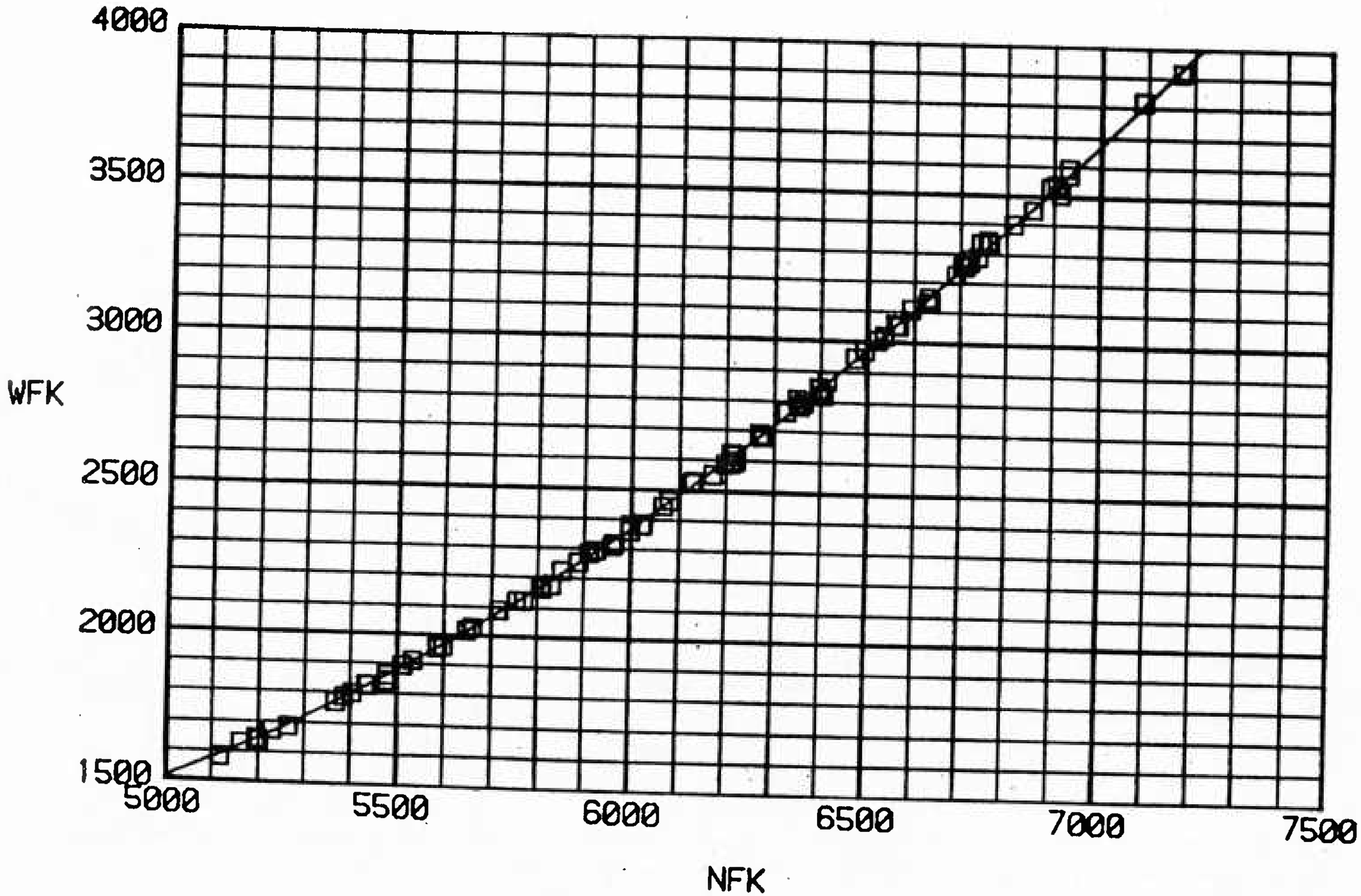

Figure 11a. Corrected fuel flow versus corrected fan speed at OTS

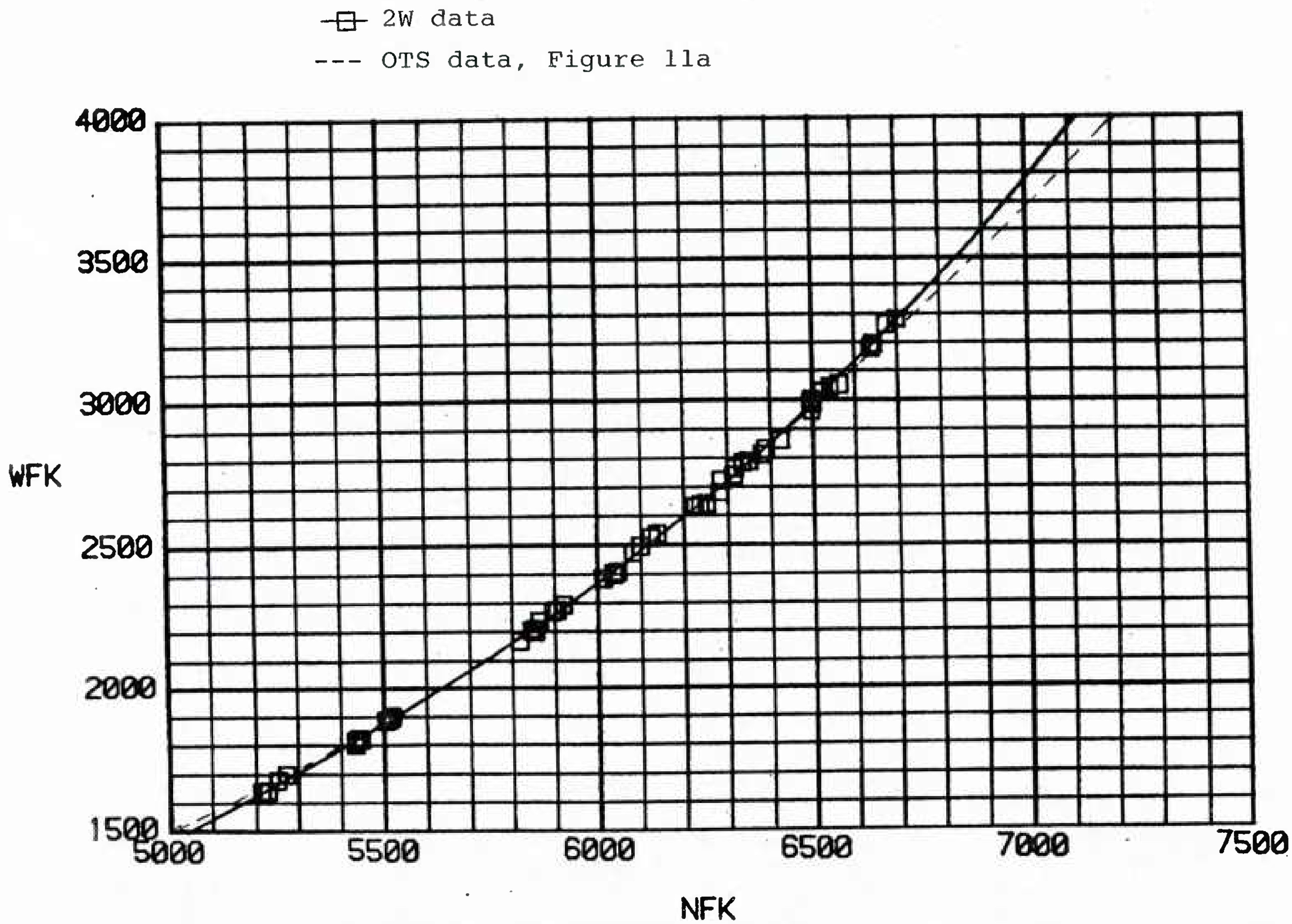

Figure 11b. Comparison of engine fuel flow at OTS and 2W

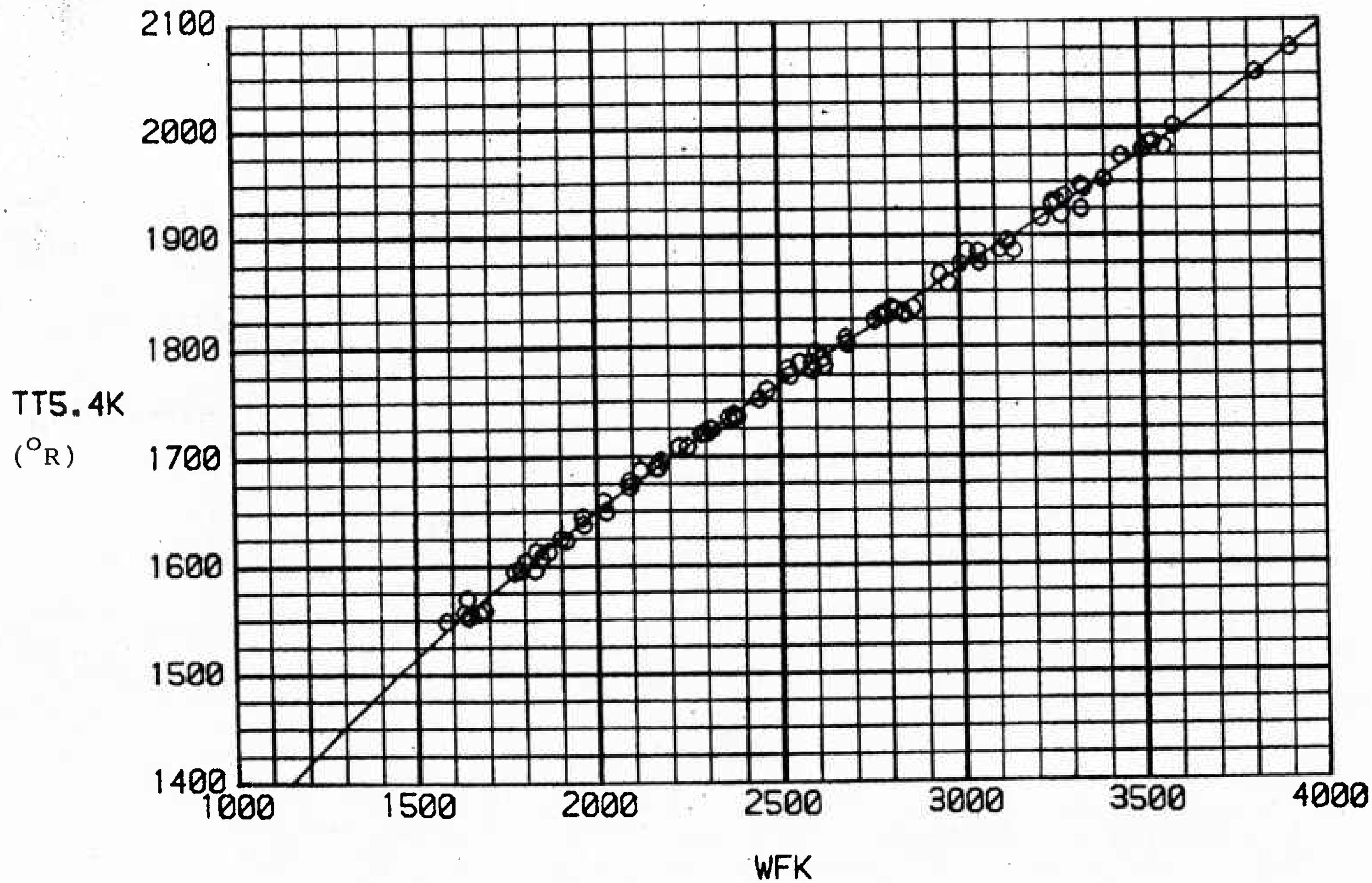

Figure 12a. Corrected low turbine inlet temperature versus corrected fuel flow at OTS

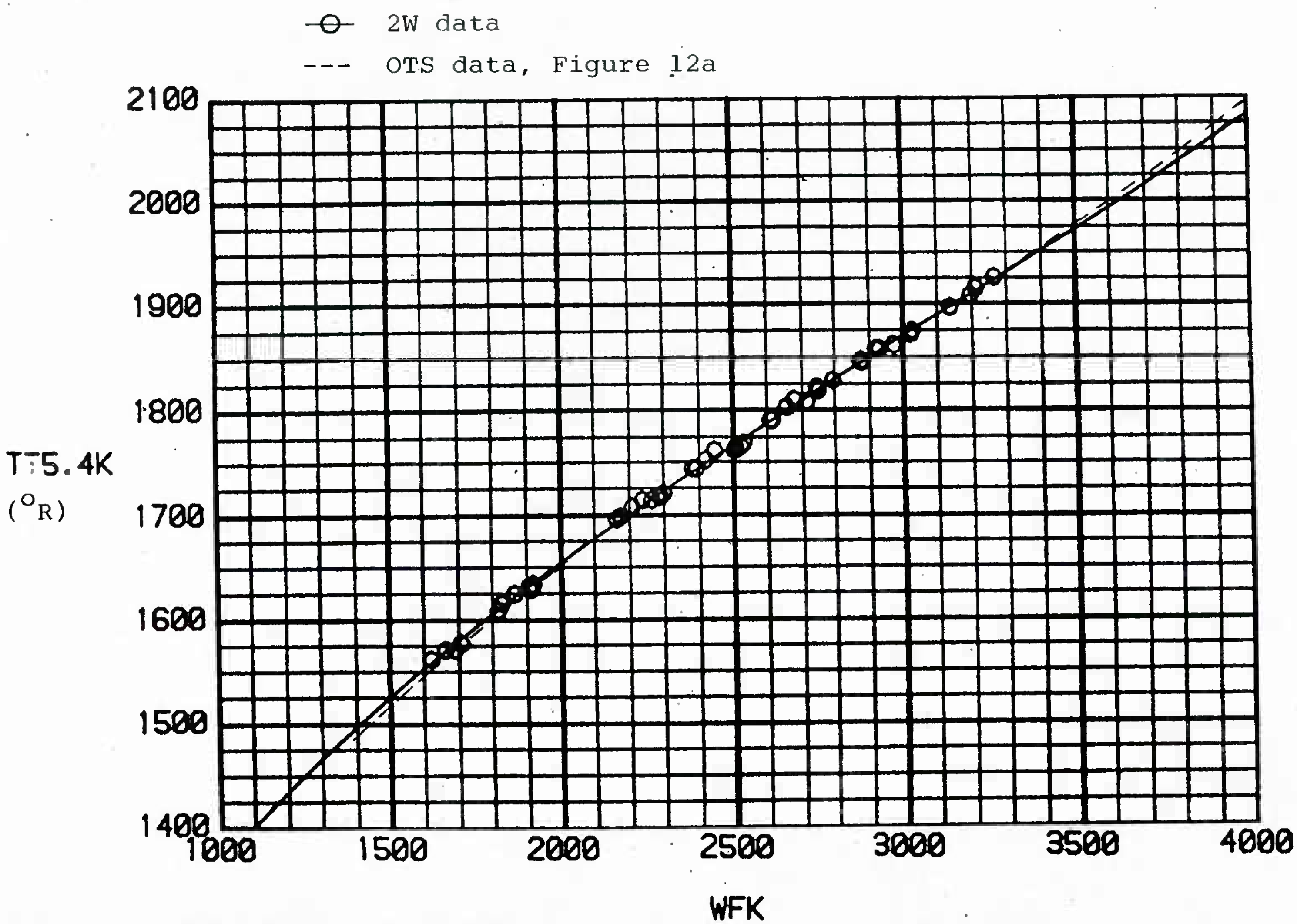

Figure 12b. Comparison of low turbine inlet temperature at OTS and 2W

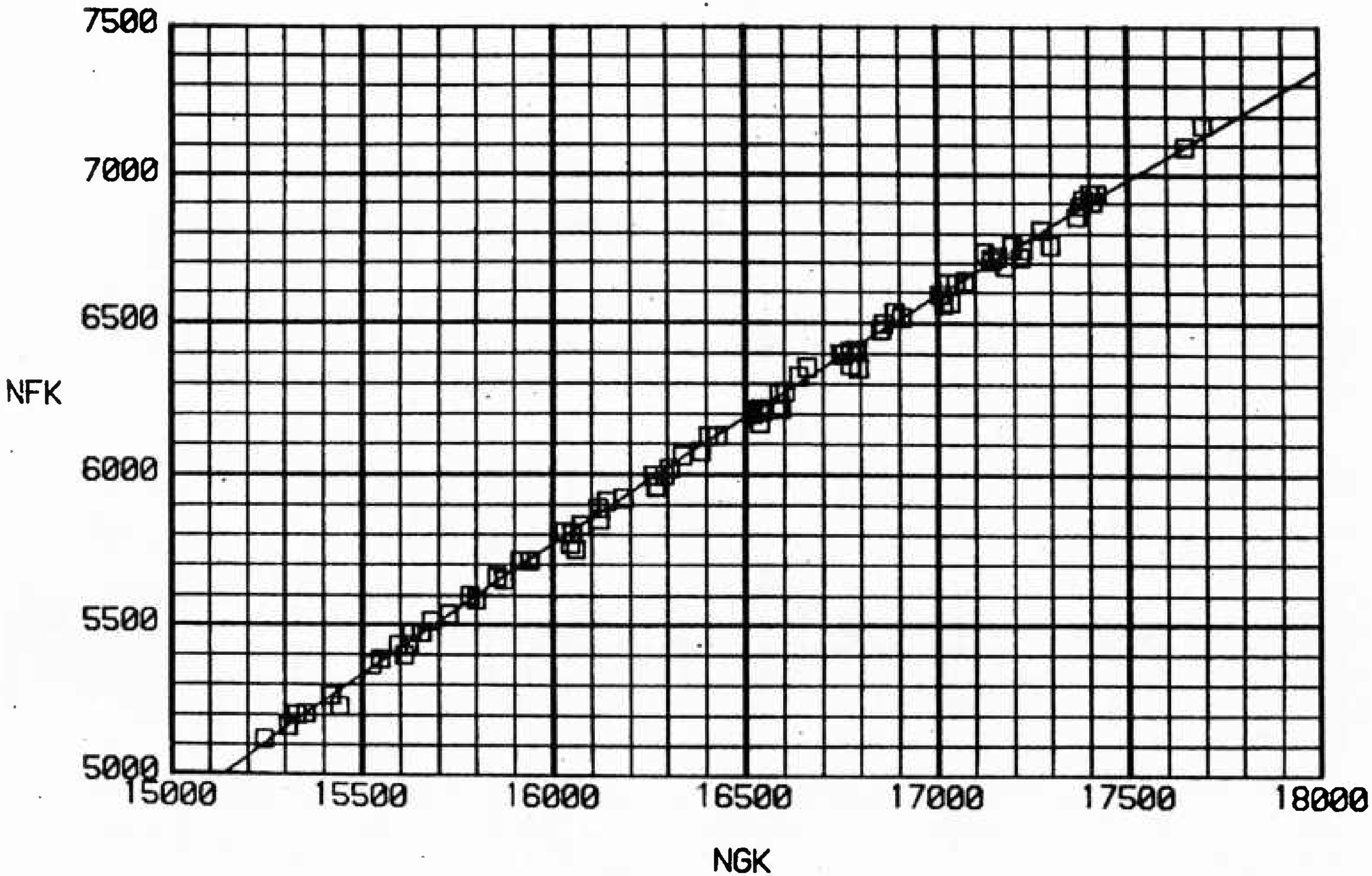

Figure 13a. Rotor speed-match at OTS

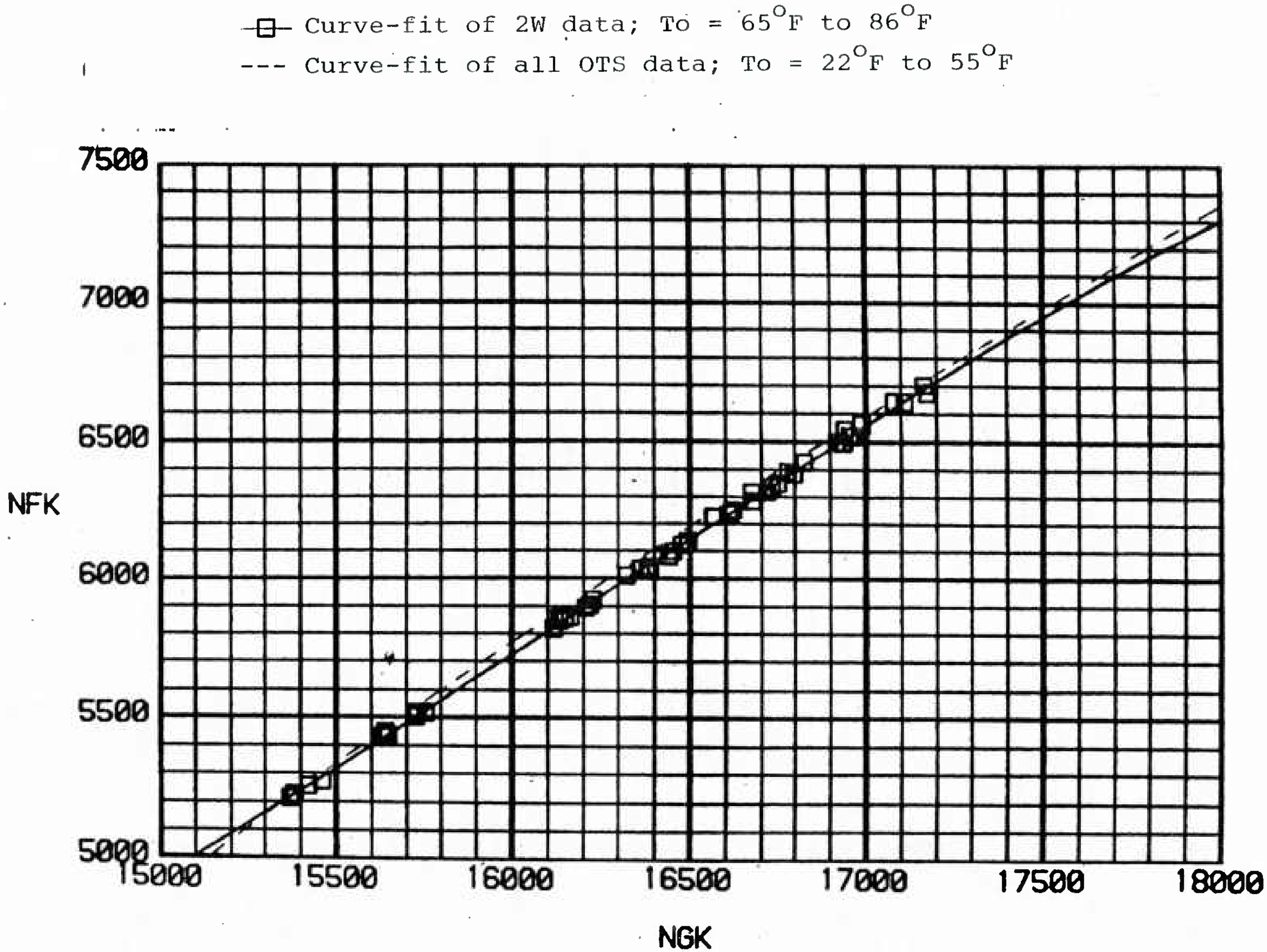

Figure 13b. Comparison of rotor speed-match at OTS and 2W

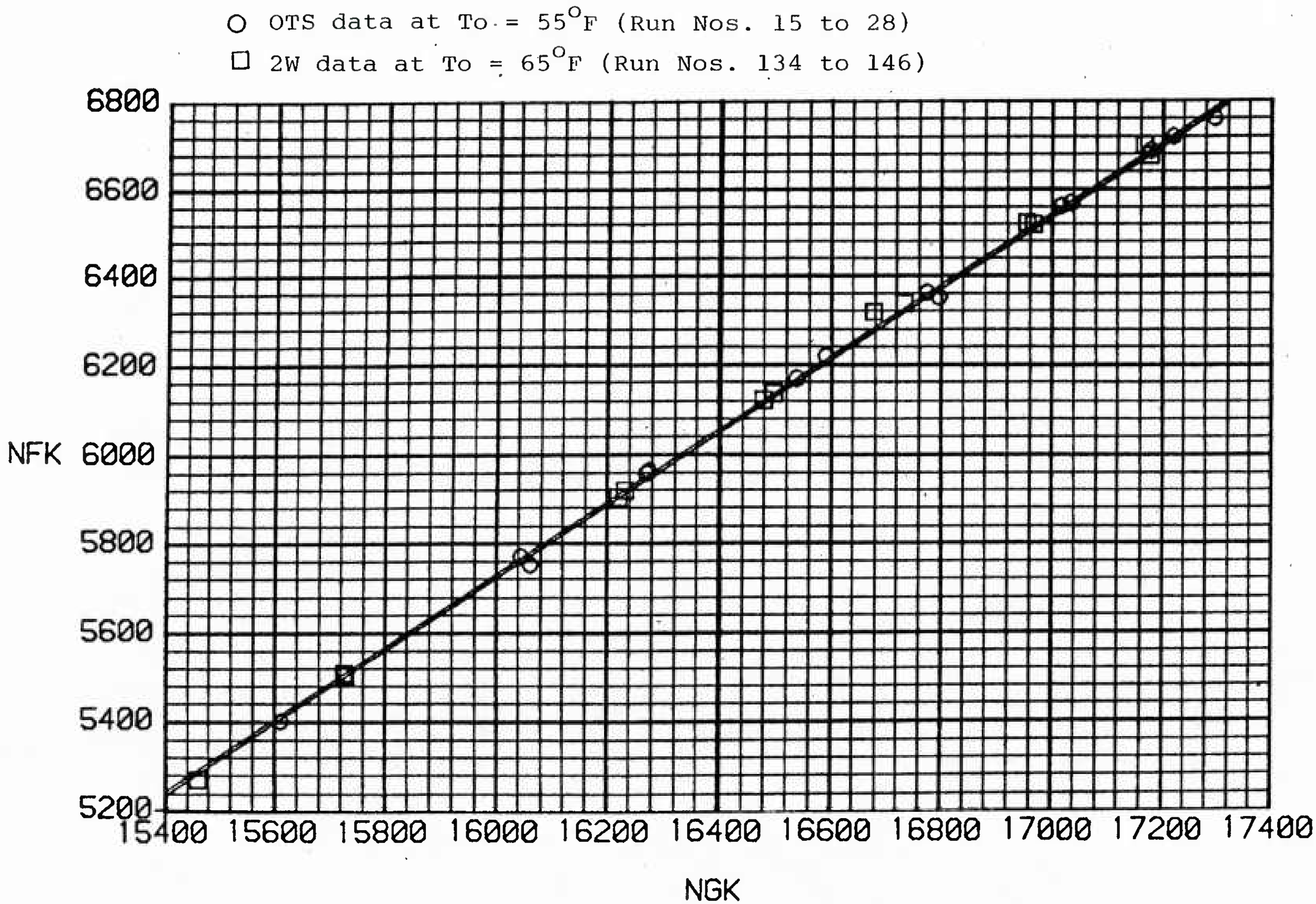

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Figure 13c. <u>Comparison of rotor speed-match at OTS and 2W at "constant" inlet temperature</u>

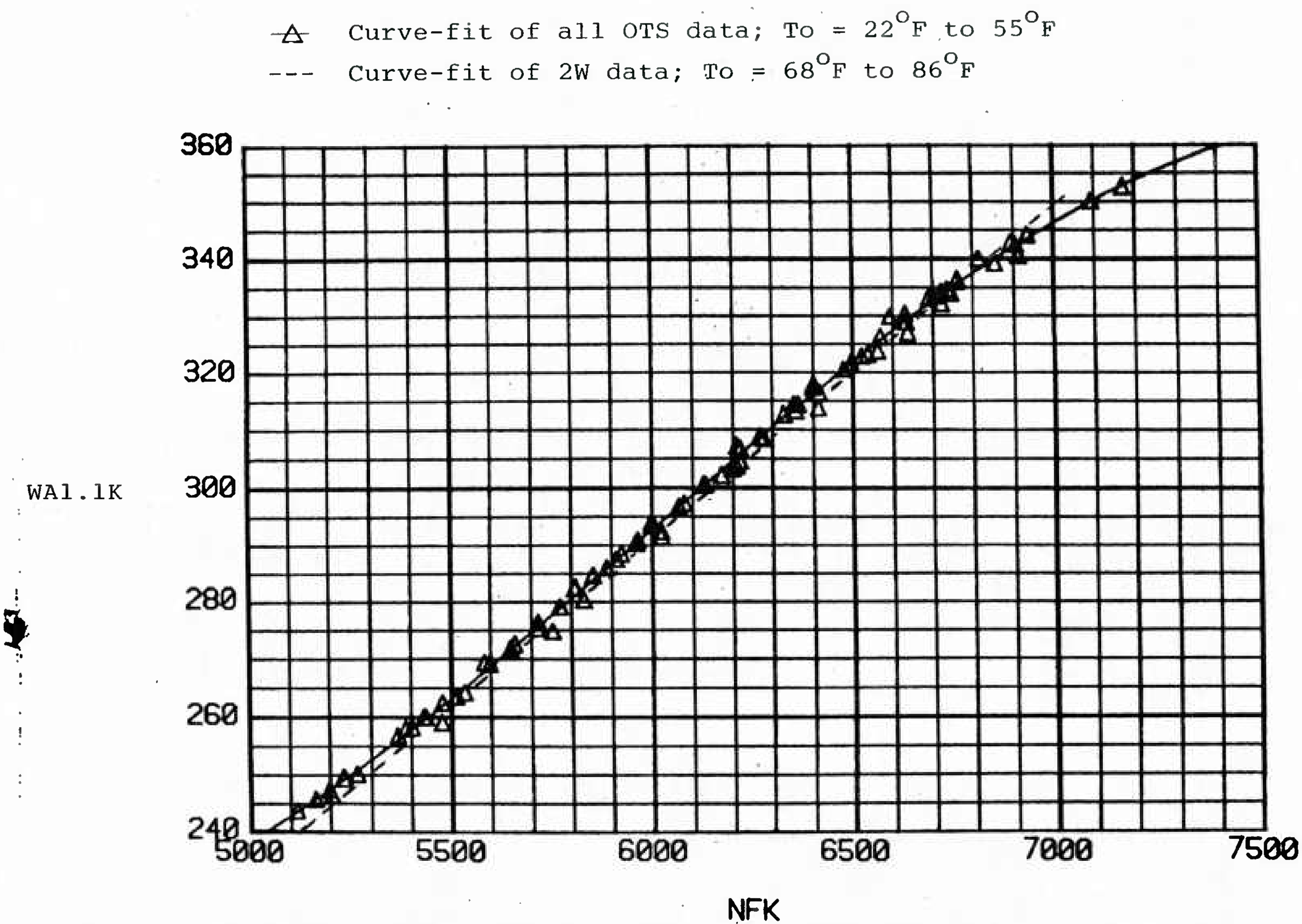

Figure 14a. Comparison of fan airflow at OTS and in 2W

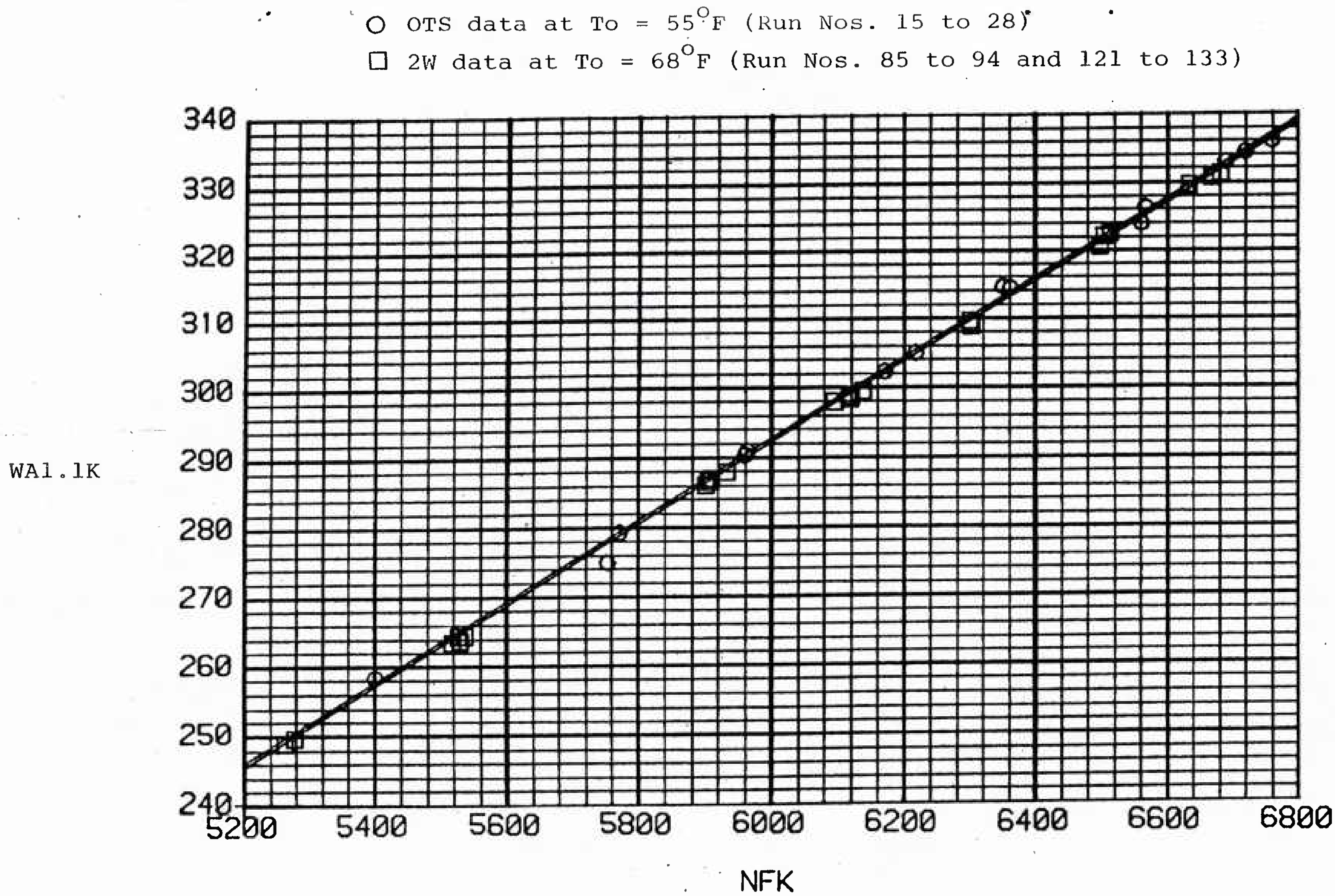

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Figure 14b. Comparison of fan airflow at OTS and in 2W at "constant" inlet temperature

~~AIRTASK~~/WORK UNIT ASSIGNMENT
NAVAIR FORM 3930/1 (REV 2-77)

DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
WASHINGTON, D.C. 20361

See NAVAIR 3900.8 or supersedure for applicable details on completing this form.

CLASSIFICATION		PAGE 1 OF 3
UNCLASSIFIED	NAPC WUA No. 463	

ADDRESSEE		AIRTASK NO.	AMEND. NO.
Commanding Officer Naval Air Propulsion Center (RM3) P.O. Box 7176 Trenton, New Jersey 08628		A5365360 052F 4W05980000	
		WORK UNIT NO. 463	AMEND. NO. B
		EFFORT LEVEL NORMAL	
NAVAIR PROJECT ENGINEER M. D. Mead, X26040	CODE AIR-5360D	CLASSIFICATION OF AT/WU UNCLASSIFIED	

1. The ~~AIRTASK~~/WORK UNIT ASSIGNMENT described below is assigned in accordance with the indicated effort level and schedule. Funding authorization for AIRTASKS will be provided in separate correspondence. If this ~~AIRTASK~~/WORK UNIT ASSIGNMENT cannot be accomplished as assigned, advise the NAVAIR HQ cognizant code. No work beyond the planning phase will be accomplished unless the addressee has funds in hand or written assurance thereof.

2. Cancellation, References and/or Enclosures.

a. References: (a) NAVAIR Work Unit Assignment No. NAPC 463 of 7 Sep 1982

3. Technical Instructions.

a. Title. DEVELOPMENT OF ALTERNATE THRUST MEASURING TECHNIQUE FOR SEA LEVEL TEST CELLS

b. Purpose. To develop an alternate method of engine thrust measurement in the sea level test cell and to improve current methods of deriving test cell thrust correction factors.

c. Background Information. Current practice for measuring engine thrust in a sea level test cell or an outdoor test stand involves a direct connection of the bellmouth to the engine. For installations in which air approach velocity ahead of the bellmouth is low (less than 5 knots) this is a convenient and accurate method. However, for higher approach velocity installations, some corrections to the measured thrust are generally necessary. The thrust correction factors for a sea level test cell may be derived empirically or by calibrating the thrust system with an engine which has well defined performance characteristics. The overall correction factor is comprised of three different forces. The inlet momentum term is generally the dominant force, and is difficult to quantify. The pressure-area force results from the static pressure gradients within the test cell and is generally a measurable quantity. Scrubbing force produced by the secondary flow is also difficult to quantify, but it is a small correction. The major difference between the altitude and sea level test cell thrust measuring systems is in

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Previous issues of this form are obsolete.

accounting for inlet momentum. Inlet momentum is measured in the altitude test cell, while in the sea level cell the thrust measurement relies on the thesis that the bellmouth suction force is balanced by the inlet momentum and the pressure-area force at the bellmouth exit.

Some disagreement in measured engine performance has been observed between different sea level and altitude test facilities. The problem appears to be more significant with the high bypass turbofan engines. Naval Air Rework Facilities (NARF) also encounter problems with calibration of production acceptance test cells due to lack of correlation engines.

This WUA provides for an experiment designed to compare measured engine performance using two different techniques in accounting for the inlet approach velocity. An engine will be tested in the NAPC outdoor test stand, and in the sea level cell with the bellmouth attached (current practice) and with the bellmouth isolated from the thrust measuring system.

Potential benefits of this program are as follows: (1) improvement of current test techniques at NAPC; (2) better definition of the factors that make up the overall sea level test cell thrust correction factor will improve test cell calibration procedures and may eventually eliminate the need for correlations of NARF test cells.

d. Detailed Requirements/Cost Estimates.

(1) Design and fabricate engine support hardware that will accommodate engine testing with the attached and isolated bellmouth configurations. The intent is to have an identical inlet flow path for both configurations. The same hardware will be used on the outdoor test stand and in the sea level test cell. The instrumentation package will include measurements of the inlet momentum downstream of the labyrinth seal, engine performance parameters, bellmouth loads and the flow field in front of and around the engine.

(2) Conduct the test in the outdoor test stand with two bellmouth configurations and analyze the results.

(3) Repeat paragraph 3d(2) testing in the sea level cell.

(4) Issue a formal report on the test results.

(5) Cost Estimate: FY 1984 - $267,000.

e. Detailed Program Plan. N/A.

f. Field Activity Contact. Roman Dejneka, PE23:RD.

g. Headquarters Technical Support. M.D. Mead, AIR-5360D.

4. Schedule.

a. Plans for FY 1983. Complete all effort described in paragraphs 3d(1) in preparation for the outdoor test.

b. Plans for FY 1984.

(1) Conduct the test in the NAPC outdoor test stand and analyze test results in the first quarter of FY 1984.

(2) Reinstall the test hardware in an NAPC sea level test cell and complete all planned testing in the first or second quarter of FY 1984.

(3) Issue a formal final report in the fourth quarter of FY 1984.

5. Reports and Documentation.

a. Reports. Informal letter progress reports shall be submitted quarterly to NAVAIR 5360D. A semiannual progress reports shall be submitted as part of the Center report to NAVAIR. An unclassified formal report will be prepared within 90 dyas of program test completion. The distribution statement to be used on the formal report is as follows: "Approved for public release; distribution unlimited." Reports will be UNCLASSIFIED.

b. Requirements for Future Planning Information. N/A

6. Contractual Authority. Contracts to perform all or portions of this WUA require prior approval of NAVAIR (AIR-536).

7. Source and Disposition of Equipment. A TF34-GE-400 engine which will be calibrated under NAPC WUA 277 will be used for this test. After completion of the test, the engine will be shipped to NARF, Alameda.

8. Aircraft Requirements. None

9. Status of Applicable Funds. Funds will be provided by Work Request.

10. Security Classification Requirements. All prescribed work to be performed under this WUA is UNCLASSIFIED.

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Addressee (4)
AIR-5360B3
AIR-620
AIR-610

APPENDIX B

DATA SYSTEM ACCURACY ESTIMATES

NAPC UNCERTAINTY PRINCIPLES

Uncertainty (μ) estimates quoted by NAPC are based on the following principles:

a. The methodology is taken from the reference Measurement Uncertainty Handbook, Dr. R. B. Abernethy, et al., Pratt and Whitney Aircraft and J. W. Thompson, Jr., ARO, Inc., revised 1980, AD-755-356, produced by the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161. The methodology is applied to specific aerodynamic parameter calculations; specifically airflow, net thrust, and thrust specific fuel consumption. (See Appendix E for various applications.)

b. The estimated precision indexes and biases of the basic measurands are given in the attached table, Data System Accuracy Estimates. The estimates are quoted for the NAPC data acquisition and measurement equipment and calibration procedures.

c. Uncertainty is an interval estimate of a reasonable limit for the largest error expected. It is similar in intent to a statistical confidence interval except that in most cases the bias contribution to the interval is based on engineering judgment. The precision part of the interval is based on statistical sampling and analysis.

d. Uncertainty quoted as a percentage means percent of the value, or point, estimated, not a percent of the full-scale value which the point might reach. In general this means that percent uncertainty estimates vary as the measurand varies.

DATA SYSTEM ACCURACY ESTIMATES

PARAMETER	FULL SCALE RANGE	RESOLUTION	PRECISION	BIAS	UNCERTAINTY
Pressure (Scanivalve Sys)	7.5 PSID	.001	.002	.004	.008 PSI
	30 PSIA	.005	.017	.005	.039 PSI
	60 PSIA	.010	.030	.013	.073 PSI
	120 PSIA	.020	.025	.021	.071 PSI
	300 PSIA	.040	.180	.086	.446 PSI
	500 PSIA	.080	.300	.105	.705 PSI
Temperature (UTR System)	Type "E"	.3	.5	1	2 ^{o}F
	Type "K"	.5	.75	2.5	4 ^{o}F
Force (Thrust and Preload)	500 LB	.1	.9	.7	2.5 LB
	1000 LB	.2	2	2	6 LB
	5000 LB	1	4.5	4	13 LB
	10000 LB	2	9	8	26 LB
	20000 LB	4	17	16	50 LB
Frequency	60000 HZ	1	.25	.5	1 HZ
Fuel Flow: *					
3/8-2.5	1000 PPH	.5	.8	.57	2.17 PPH
3/8-5	2000 PPH	1	1.5	1	4 PPH
1/2-10	4000 PPH	2	2.5	2	7 PPH
5/8-15	6000 PPH	3	3.5	3	10 PPH
3/4-25	10000 PPH	5	5	5	15 PPH
1-50	20000 PPH	10	10	10	30 PPH
1 1/4-75	30000 PPH	15	15	15	45 PPH
1 1/2-125	50000 PPH	25	25	25	75 PPH
2-225	90000 PPH	45	45	45	135 PPH

* Fuel Flow uncertainty holds for 10 to 100 percent of full scale range.

Definitions of the terms used are:

a. Resolution: The smallest change in value that can be detected by the data system.

b. Precision: The variation demonstrated by repeated measurements. (Often referred to as standard deviation.)

c. Bias: Fixed or systematic error. (Value generally based on sound engineering judgment.)

d. Uncertainty: An expression of a reasonable limit for the largest error to be expected. Uncertainty is equal to the Bias plus a multiple of the Precision. (The multiplier decreases to 2.0 as the number of samples increases.)

TF34 CORRELATION TEST

	NFK	NGK	WFK	FNK	SFCK	TT54K	BAR	P2	Pamb	T2	WA1.1K	P2.4/P2	COMMENTS
1	6855	17366	3448	9361	0.368337	1974	29.906	29.861		49.5	339.2	1.480	OTS, ISOLATED BELLMOUTH
2	6637	17075	3131	8672	0.361047	1896	29.908	29.866		49.5	327.0	1.446	26 JANUARY 1984
3	6410	16773	2823	7970	0.354203	1833	29.911	29.873		49.0	314.0	1.406	
4	6200	16523	2591	7396	0.350324	1780	29.913	29.879		50.0	303.6	1.376	
5	6024	16305	2385	6846	0.348379	1738	29.913	29.885		49.0	291.6	1.350	
6	5831	16075	2179	6283	0.346809	1696	29.916	29.891		48.0	280.5	1.318	
7	6023	16305	2380	6836	0.348157	1739	29.916	29.890		48.0	292.5	1.349	
8	6211	16522	2592	7412	0.349703	1786	29.918	29.855		49.0	303.9	1.378	
9	6414	16793	2871	8053	0.356513	1835	29.911	29.880		48.0	316.6	1.409	
10	6634	17051	3150	8737	0.360536	1886	29.913	29.882		48.0	329.0	1.447	
11	6745	17228	3337	9079	0.367551	1925	29.918	29.889		48.0	334.0	1.467	
12	6914	17384	3508	9443	0.371492	1980	29.921	29.864		48.0	340.5	1.487	
13	5477	15630	1845	5353	0.344667	1608	29.926	29.896		48.0	259.1	1.270	
14	6722	17160	3279	8977	0.365267	1920	29.933	29.883		48.0	332.1	1.462	
15	6720	17221	3268	8956	0.364895	1931	30.012	29.938		55.0	334.3	1.462	OTS, ISOLATED BELLMOUTH
16	6568	17035	3052	8509	0.358679	1885	30.012	29.953		54.5	326.3	1.436	27 JANUARY 1984
17	6351	16795	2809	7918	0.354761	1835	30.012	29.917		55.5	314.5	1.406	
18	6219	16593	2602	7402	0.351527	1796	30.012	29.958		54.0	304.9	1.379	
19	5964	16275	2320	6703	0.346114	1725	30.012	29.923		55.0	291.1	1.344	
20	5755	16061	2123	6078	0.349293	1689	30.012	29.926		55.0	275.1	1.311	
21	5401	15612	1799	5267	0.341561	1604	30.012	29.926		56.0	258.4	1.265	
22	5771	16046	2123	6174	0.343861	1687	29.995	29.933		55.5	279.4	1.313	
23	5960	16270	2311	6663	0.346841	1725	29.995	29.933		55.0	290.4	1.341	
24	6171	16538	2555	7279	0.351010	1786	29.995	29.933		55.0	302.4	1.373	
25	6363	16774	2794	7894	0.353940	1829	29.995	29.950		55.0	314.5	1.403	
26	6562	17019	3057	8443	0.362075	1876	29.995	29.923		55.0	323.9	1.436	
27	6690	17179	3226	8873	0.363575	1917	29.995	29.917		55.0	333.1	1.458	
28	6760	17298	3344	9068	0.368769	1944	29.995	29.908		54.0	336.0	1.467	
29	5232	15444	1672	4878	0.342763	1557	29.930	29.895		21.8	249.4	1.241	OTS, DIRECT CONNECT
30	5535	15728	1913	5560	0.344065	1624	29.930	29.876		22.0	264.4	1.278	1 FEBUARY 1984
31	5715	15939	2090	6046	0.345683	1678	29.932	29.890		23.0	276.6	1.305	
32	5925	16184	2298	6509	0.353050	1722	29.935	29.885		21.5	288.5	1.335	
33	6128	16427	2525	7160	0.352654	1781	29.930	29.880		22.0	300.7	1.366	
34	6354	16663	2784	7823	0.355874	1830	29.935	29.880		23.1	313.4	1.401	
35	6522	16907	3005	8354	0.359708	1875	29.937	29.880		22.9	322.9	1.430	
36	6763	17199	3337	9165	0.364103	1947	29.942	29.890		22.4	336.5	1.468	
37	6934	17421	3594	9467	0.379635	2003	29.942	29.885		22.5	344.4	1.494	
38	7172	17698	3920	10147	0.386321	2075	29.952	29.895		23.3	352.7	1.521	
39	6934	17402	3570	9572	0.372963	1983	29.950	29.900		22.6	344.1	1.492	
40	6738	17125	3290	9004	0.365393	1936	29.950	29.900		23.2	334.8	1.463	
41	6537	16887	3023	8447	0.357879	1887	29.960	29.890		22.8	323.2	1.431	
42	6329	16640	2765	7728	0.357790	1824	29.957	29.910		22.5	312.7	1.398	
43	6131	16405	2531	7101	0.356429	1775	29.965	29.930		22.2	300.9	1.367	
44	5912	16140	2287	6563	0.348469	1721	29.972	29.930		21.9	287.7	1.333	
45	5717	15915	2090	6043	0.345855	1673	29.975	29.926		21.8	275.4	1.304	
46	5511	15680	1897	5491	0.345474	1626	29.977	29.945		21.5	263.7	1.275	
47	5162	15306	1627	4772	0.340947	1557	30.164	30.135		40.0	245.9	1.236	OTS, DIRECT CONNECT
48	5477	15656	1862	5336	0.348951	1614	30.159	30.135		40.0	262.6	1.273	2 FEBUARY 1984
49	5201	15351	1635	4719	0.346472	1570	30.159	30.135		35.0	246.6	1.236	
50	5431	15622	1828	5244	0.348589	1613	30.159	30.130		34.4	260.0	1.266	
51	5648	15872	2018	5772	0.349619	1660	30.164	30.135		34.0	272.1	1.296	
52	5852	16121	2227	6274	0.354957	1710	30.169	30.135		33.4	284.8	1.326	

TF34 CORRELATION TEST

	NFK	NGK	WFK	FNK	SFCK	TT54K	BAR	P2	Pamb	T2	WA1.1K	P2.4/P2	COMMENTS
53	6079	16384	2465	6920	0.356214	1761	30.167	30.130		32.8	297.5	1.360	
54	6277	16606	2684	7564	0.354839	1809	30.172	30.140		31.9	308.8	1.389	
55	6476	16851	2946	8186	0.359883	1866	30.172	30.135		31.3	320.7	1.422	
56	6707	17144	3258	8900	0.366067	1929	30.177	30.145		30.3	333.6	1.459	
57	6907	17410	3537	9436	0.374841	1988	30.172	30.135		29.0	342.7	1.488	
58	7093	17651	3821	9909	0.385609	2053	30.174	30.135		29.0	350.3	1.513	
59	6895	17376	3527	9421	0.374376	1986	30.177	30.135		30.2	342.9	1.488	
60	6712	17145	3257	8845	0.368231	1931	30.177	30.130		28.0	333.5	1.458	
61	6496	16858	2971	8249	0.360165	1857	30.177	30.145		30.1	321.9	1.426	
62	6270	16589	2691	7558	0.356047	1803	30.177	30.145		30.1	308.9	1.389	
63	6066	16338	2448	6972	0.351119	1753	30.174	30.145		29.9	296.9	1.357	
64	5888	16118	2251	6456	0.348668	1710	30.174	30.145		29.4	286.2	1.330	
65	5659	15853	2026	5856	0.345970	1651	30.177	30.150		29.5	272.8	1.297	
66	5435	15595	1827	5302	0.344587	1596	30.174	30.150		29.6	260.0	1.266	
67	5264	15419	1685	4895	0.344229	1560	30.177	30.150		29.6	250.1	1.244	
68	5116	15243	1581	4562	0.346559	1549	30.074	30.045		40.3	243.8	1.229	OTS, DIRECT & WRAP
69	5365	15525	1768	5168	0.342105	1595	30.069	30.040		42.3	256.9	1.259	9 FEBUARY 1984
70	5584	15797	1958	5680	0.344718	1645	30.064	30.040		41.2	269.6	1.290	
71	5805	16050	2171	6240	0.347917	1690	30.067	30.040		40.7	282.5	1.320	
72	5998	16292	2380	6725	0.353903	1736	30.062	30.035		41.4	294.2	1.351	
73	6210	16542	2625	7411	0.354203	1784	30.062	30.030		41.6	307.3	1.383	
74	6398	16756	2848	8026	0.354847	1830	30.064	30.020		42.5	318.2	1.412	
75	6594	17007	3112	8663	0.359229	1888	30.064	30.020		43.8	329.9	1.447	
76	6813	17275	3401	9207	0.369393	1952	30.069	30.030		41.9	340.1	1.479	
77	6632	17030	3131	8703	0.359761	1894	30.074	30.030		42.3	330.3	1.448	
78	6400	16747	2844	7982	0.356302	1831	30.067	30.025		42.1	317.6	1.411	
79	6219	16541	2621	7444	0.352096	1790	30.072	30.035		41.1	306.8	1.383	
80	5998	16262	2362	6715	0.351750	1736	30.069	30.045		41.9	293.6	1.350	
81	5809	16029	2163	6305	0.343061	1690	30.077	30.040		42.1	282.8	1.319	
82	5597	15782	1963	5666	0.346453	1639	30.079	30.050		41.7	269.3	1.290	
83	5385	15545	1788	5196	0.344111	1597	30.084	30.055		41.8	258.0	1.262	
84	5196	15328	1640	4711	0.348121	1553	30.084	30.065		42.1	247.5	1.239	
85	6138	16488	2532	7182	0.352548	1769	29.836	29.729	29.744	67.7	299.5	1.367	ISOLATED BELLMOUTH, 2W
86	5934	16234	2301	6609	0.348162	1722	29.829	29.735	29.741	66.5	288.0	1.336	EJECTOR AFT
87	5528	15745	1905	5537	0.344049	1632	29.826	29.747	29.766	67.3	264.4	1.280	21 MAY 1984
88	5262	15418	1685	4905	0.343527	1572	29.831	29.756	29.770	67.9	249.1	1.248	
89	5538	15767	1914	5550	0.344865	1632	29.834	29.757	29.772	68.2	264.4	1.280	
90	5902	16194	2267	6518	0.347806	1715	29.828	29.728	29.744	68.6	286.2	1.330	
91	6120	16462	2506	7133	0.351325	1765	29.828	29.727	29.741	68.6	298.7	1.363	
92	6302	16665	2716	7678	0.353738	1809	29.828	29.711	29.727	69.5	308.9	1.391	
93	6499	16908	2972	8274	0.359197	1861	29.829	29.711	29.733	69.2	320.6	1.424	
94	6669	17124	3214	8825	0.364193	1915	29.834	29.696	29.723	69.4	330.7	1.452	
95	6624	17070	3138	8639	0.363236	1897	29.926	29.750	29.801	73.0	326.7	1.442	ISOLATED BELLMOUTH, 2W
96	6473	16887	2931	8184	0.358138	1858	29.925	29.767	29.821	73.5	318.1	1.418	EJECTOR AFT
97	6269	16631	2678	7553	0.354561	1810	29.921	29.778	29.822	73.4	305.8	1.384	22 MAY 1984
98	6076	16404	2447	6986	0.350272	1762	29.923	29.792	29.818	74.3	294.8	1.354	
99	5881	16169	2239	6436	0.347887	1715	29.919	29.799	29.842	75.1	283.7	1.323	
100	5486	15710	1862	5415	0.343860	1626	29.916	29.807	29.839	75.4	260.9	1.271	
101	5235	15389	1658	4817	0.344198	1572	29.915	29.817	29.853	76.6	246.4	1.241	
102	5486	15719	1863	5410	0.344362	1626	29.911	29.802	29.846	76.4	260.8	1.270	
103	5852	16150	2207	6351	0.347504	1708	29.911	29.783	29.830	77.8	282.0	1.319	
104	6055	16388	2419	6909	0.350123	1753	29.912	29.770	29.818	77.4	293.3	1.351	

TF34 CORRELATION TEST

	NFK	NGK	WFK	FNK	SFCK	TT54K	BAR	P2	Pamb	T2	WA1.1K	P2.4/P2	COMMENTS
105	6256	16632	2656	7513	0.353521	1804	29.905	29.758	29.811	79.0	305.3	1.382	
106	6430	16836	2878	8057	0.357205	1847	29.906	29.754	29.796	79.0	315.6	1.410	
107	6535	16979	3022	8398	0.359848	1872	29.904	29.727	29.781	79.6	322.2	1.431	
108	6460	16892	2919	8128	0.359129	1857	29.893	29.737	29.786	84.7	317.3	1.418	ISOLATED BELLMOUTH, 2W
109	6325	16726	2745	7739	0.354697	1822	29.879	29.717	29.767	85.2	309.6	1.395	EJECTOR FWD.
110	6215	16608	2615	7399	0.353426	1792	29.880	29.727	29.760	85.6	302.8	1.378	22 MAY 1984
111	6016	16357	2382	6812	0.349677	1746	29.874	29.740	29.779	85.5	291.5	1.347	
112	5818	16119	2174	6256	0.347506	1699	29.875	29.751	29.783	86.4	279.7	1.315	
113	5443	15662	1824	5299	0.344216	1616	29.871	29.758	29.786	85.7	257.3	1.265	
114	5187	15366	1617	4706	0.343604	1562	29.870	29.769	29.803	85.3	243.1	1.236	
115	5434	15663	1816	5274	0.344331	1610	29.871	29.766	29.778	86.0	256.6	1.263	
116	5802	16103	2163	6220	0.347749	1696	29.869	29.746	29.781	86.4	278.6	1.312	
117	6023	16376	2393	6829	0.350417	1745	29.869	29.739	29.762	85.8	291.5	1.347	
118	6208	16600	2609	7375	0.353763	1791	29.869	29.713	29.760	85.8	302.3	1.376	
119	6354	16781	2795	7834	0.356778	1829	29.860	29.700	29.742	86.2	311.0	1.399	
120	6421	16863	2880	8066	0.357054	1846	29.858	29.685	29.711	86.7	315.0	1.411	
121	6682	17150	3264	8915	0.366125	1926	29.930	29.750	29.796	67.0	331.3	1.460	ISOLATED BELLMOUTH, 2W
122	6516	16948	3028	8408	0.360133	1874	29.926	29.755	29.819	67.5	322.5	1.434	EJECTOR FWD.
123	6300	16663	2746	7738	0.354872	1820	29.925	29.772	29.811	67.7	309.1	1.396	24 MAY 1984
124	6119	16472	2524	7183	0.351385	1767	29.930	29.787	29.834	67.7	298.4	1.367	
125	5911	16212	2293	6610	0.346899	1719	29.932	29.805	29.824	67.8	287.0	1.333	
126	5530	15742	1917	5561	0.344722	1634	29.927	29.815	29.840	68.1	263.8	1.280	
127	5279	15455	1706	4974	0.342984	1578	29.925	29.829	29.847	68.4	249.7	1.249	
128	5519	15751	1910	5536	0.345014	1629	29.922	29.811	29.846	68.4	263.5	1.279	
129	5907	16219	2289	6582	0.347767	1718	29.917	29.784	29.823	68.9	286.7	1.334	
130	6095	16446	2503	7125	0.351298	1763	29.914	29.775	29.829	69.8	298.0	1.364	
131	6300	16692	2750	7761	0.354336	1819	29.917	29.766	29.801	68.5	309.7	1.396	
132	6506	16950	3020	8413	0.358968	1872	29.919	29.749	29.806	68.8	322.2	1.432	
133	6634	17106	3197	8799	0.363337	1909	29.922	29.737	29.795	69.7	329.6	1.452	
134	6700	17167	3279	8567	0.382748	1936	29.635	29.481	29.479	64.1		1.461	ATTACHED BELLMOUTH, 2W
135	6523	16957	3025	8051	0.375730	1883	29.631	29.474	29.473	64.1		1.433	(NO WA1.1)
136	6317	16677	2741	7373	0.371762	1829	29.630	29.504	29.488	64.0		1.395	EJECTOR FWD.
137	6138	16498	2541	6926	0.366878	1787	29.627	29.506	29.499	64.3		1.368	1 JUNE 1984 AM
138	5921	16231	2298	6299	0.364820	1736	29.615	29.495	29.488	64.5		1.337	
139	5511	15725	1893	5240	0.361260	1639	29.613	29.523	29.510	65.6		1.279	
140	5273	15459	1696	4741	0.357730	1579	29.612	29.520	29.517	65.7		1.251	
141	5503	15728	1884	5224	0.360643	1632	29.616	29.510	29.516	66.4		1.278	
142	5905	16221	2277	6275	0.362869	1729	29.607	29.489	29.488	66.0		1.335	
143	6123	16480	2526	6907	0.365716	1784	29.605	29.475	29.467	66.1		1.369	
144	6338	16734	2783	7510	0.370573	1835	29.613	29.479	29.476	66.2		1.401	
145	6519	16969	3029	8063	0.375667	1882	29.609	29.466	29.469	66.2		1.435	
146	6675	17178	3266	8534	0.382704	1928	29.607	29.442	29.462	66.7		1.462	
147	6645	17083	3197	8400	0.380595	1916	29.537	29.383	29.389	69.8		1.452	ATTACHED BELLMOUTH, 2W
148	6498	16938	3001	7998	0.375219	1872	29.534	29.384	29.391	69.8		1.430	(NO WA1.1)
149	6319	16719	2766	7416	0.372977	1829	29.528	29.387	29.385	70.4		1.399	EJECTOR, FWD.
150	6101	16453	2498	6797	0.367515	1776	29.535	29.380	29.393	70.7		1.364	1 JUNE 1984 PM
151	5895	16210	2272	6223	0.365097	1723	29.527	29.414	29.407	70.2		1.333	
152	5517	15731	1897	5261	0.360578	1633	29.524	29.432	29.418	71.3		1.278	
153	5253	15420	1678	4693	0.357554	1577	29.519	29.420	29.429	71.0		1.247	
154	5520	15756	1903	5249	0.362545	1633	29.522	29.416	29.417	70.6		1.280	
155	5863	16167	2237	6130	0.364927	1711	29.517	29.397	29.399	71.4		1.328	
156	6082	16441	2475	6754	0.366450	1765	29.516	29.402	29.377	71.3		1.360	

TF34 CORRELATION TEST

	NFK	NGK	WFK	FNK	SFCK	TT54K	BAR	P2	Pamb	T2	WA1.1K	P2.4/P2	COMMENTS
157	6287	16679	2723	7324	0.371791	1812	29.519	29.387	29.390	71.2		1.393	
158	6457	16937	2990	7955	0.375864	1863	29.513	29.375	29.357	71.2		1.428	
159	6641	17113	3183	8413	0.378343	1904	29.518	29.382	29.386	70.5		1.450	
160	6543	16942	3042	8112	0.375000	1884	29.743	29.594	29.622	80.6		1.441	ATTACHED BELLMOUTH, 2W
161	6392	16781	2832	7659	0.369761	1838	29.741	29.591	29.610	80.8		1.413	EJECTOR AFT
162	6227	16567	2635	7213	0.365313	1802	29.743	29.587	29.612	81.5		1.387	4 JUNE 1984
163	6014	16324	2387	6565	0.363595	1746	29.735	29.606	29.634	82.5		1.352	
164	5846	16135	2204	6117	0.360307	1707	29.741	29.608	29.629	82.2		1.326	
165	5440	15646	1823	5092	0.358013	1616	29.733	29.620	29.647	81.6		1.273	
166	5214	15369	1638	4599	0.356164	1568	29.736	29.643	29.667	81.5		1.245	
167	5432	15645	1814	5068	0.357932	1614	29.733	29.633	29.642	82.0		1.272	
168	6038	16362	2400	6629	0.362046	1752	29.733	29.598	29.606	81.7		1.356	
169	6238	16613	2640	7213	0.366006	1802	29.735	29.599	29.608	81.7		1.388	
170	6351	16750	2790	7529	0.370567	1835	29.732	29.574	29.609	82.2		1.408	
171	6502	16921	2986	8033	0.371717	1875	29.738	29.556	29.590	82.2		1.432	
172	5855	16136	2210	6135	0.360228	1713	29.729	29.608	29.631	82.2		1.328	
173	6565	16989	3055	8129	0.375815	1888	29.936	29.724	29.815	79.1		1.440	ATTACHED BELLMOUTH, 2W
174	6425	16828	2862	7689	0.372220	1843	29.931	29.794	29.823	79.7		1.417	EJECTOR AFT
175	6253	16623	2645	7200	0.367361	1803	29.939	29.790	29.811	78.8		1.388	5 JUNE 1984
176	6046	16387	2410	6600	0.365152	1755	29.935	29.796	29.818	79.6		1.356	
177	5855	16151	2202	6070	0.362768	1714	29.938	29.807	29.826	79.4		1.327	
178	5447	15639	1819	5089	0.357438	1618	29.936	29.827	29.848	80.9		1.273	
179	5228	15383	1639	4622	0.354608	1569	29.939	29.848	29.860	78.6		1.246	
180	5431	15633	1802	5043	0.357327	1614	29.935	29.836	29.857	82.1		1.269	
181	5819	16120	2167	5966	0.363225	1700	29.937	29.807	29.831	81.7		1.319	
182	6036	16384	2402	6617	0.363004	1752	29.931	29.807	29.823	81.2		1.355	
183	6283	16675	2683	7290	0.368038	1812	29.931	29.807	29.833	78.1		1.391	
184	6383	16797	2812	7577	0.371123	1837	29.931	29.782	29.794	81.7		1.408	
185	6498	16937	2962	7960	0.372111	1866	29.929	29.771	29.785	82.3		1.429	

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